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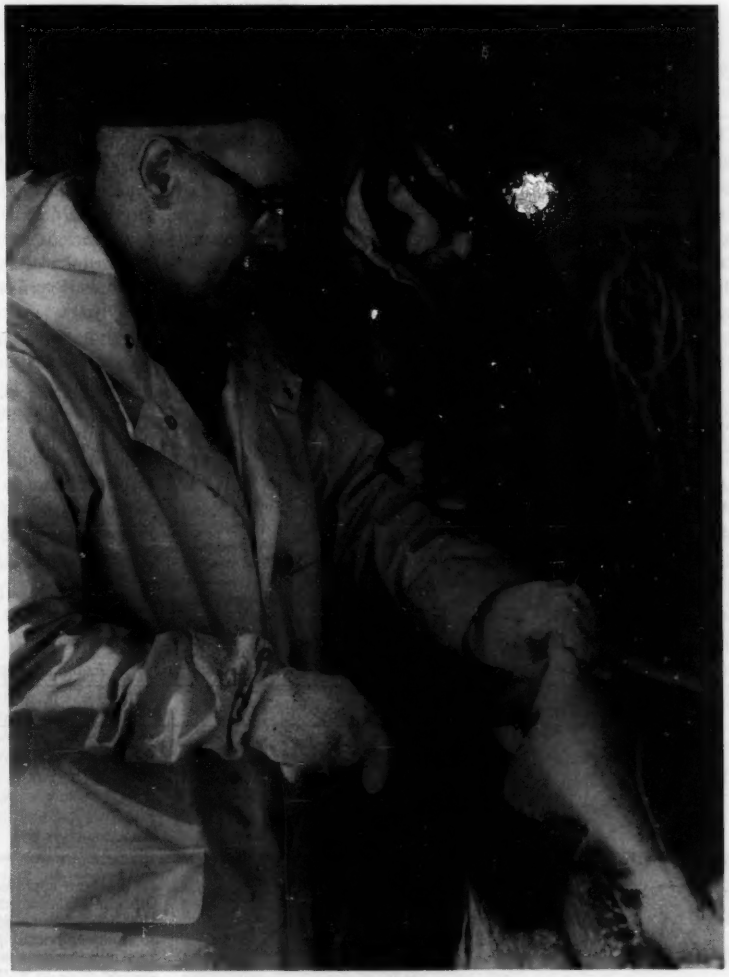

Atlantic Cod Preservation

Marine Fisheries REVIEW

On the cover: Gutting an Atlantic cod. BCF photograph by Robert K. Brigham, Woods Hole, Mass.

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Anadromous Brook Charr, *Salvelinus fontinalis:* Opportunities and Constraints for Population Enhancement

ROBERT J. NAIMAN, STEPHEN D. MCCORMICK,
W. LINN MONTGOMERY, and RODERICK MORIN

Introduction

Success of enhancement programs depends largely on the efficient use of natural factors rendering a species suitable for a particular form of culture and management (Bardach et al., 1972). Most efforts to enhance anadromous species have been directed toward commercial species with proven marketability. These species, however, are not necessarily the most efficient in dealing with vagaries of the natural environment. Inability to control natural environmental factors introduces significant unpredictability into fisheries enhancement and aquaculture.

Anadromous brook charr, *Salvelinus fontinalis*, have some characteristics favorable for enhancement and aquaculture which will be reviewed in this article. Throughout most of their natural range, they enter salt water, where accessible, and grow rapidly while at sea. They have well developed homing abilities, migrating seasonally at precise periods. At sea they stay near their natal river, remaining in salt water for periods usually no greater than 4-5 months. Within their native freshwater range, they do not appear to compete significantly with native salmon or trout for space and resources. Lastly, charr are popular recreational fishes and could have some commercial potential. At present, brook charr are of importance in recreational freshwater fisheries and aquaculture, but their enhancement and utilization in marine systems remains largely unexplored (Power, 1980).

The objectives of this article are to summarize studies initiated by Gibson and Whoriskey (1980) on anadromy in brook charr, and continued by us, on the North Shore of the Gulf of St. Lawrence near Sept-Iles, Quebec; to compare our results with those reported for other populations; and to make recommendations for enhancement of the fishery. For 5 years we have examined the ecology of anadromous and freshwater populations of brook charr, and have experimentally explored their growth and survival in seawater. Aspects of this study have been presented elsewhere on induction of anadromy and experimental sea ranching (Gibson and Whoriskey, 1980; Whoriskey et al., 1981a, b), parasites (Black, 1981; Black et al., 1983), migration and ecology (Montgomery et al., 1983), and osmoregulatory physiology (McCormick and Naiman 1984a, b, 1985a, b; McCormick et al. 1985). These studies, combined with previous ecological in-

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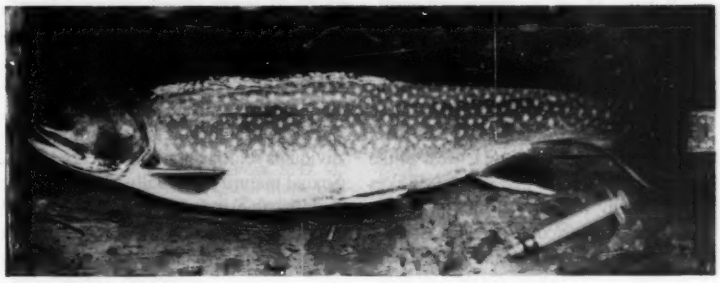
ABSTRACT—We present an overview of studies conducted during 1978-84 on anadromous brook charr, Salvelinus fontinalis, *near Sept-Iles, Quebec, Can. Studies on experimental sea ranching are integrated with those on the biology of anadromous stocks, results are compared with those reported for other anadromous and nonanadromous stocks, and recommendations are made for population enhancement. Anadromous brook charr exhibit short but synchronized migratory movements, can enter brackish water at a small size, remain in coastal waters, grow rapidly while at sea, home effectively, and provide a potentially high yield to recreational and commercial fisheries. We suggest that anadromous brook charr, and possibly other members of the genus* Salvelinus, *are reasonable candidates for local enhancement of coastal or estuarine salmonid fisheries and for sea ranching in northern latitudes.*



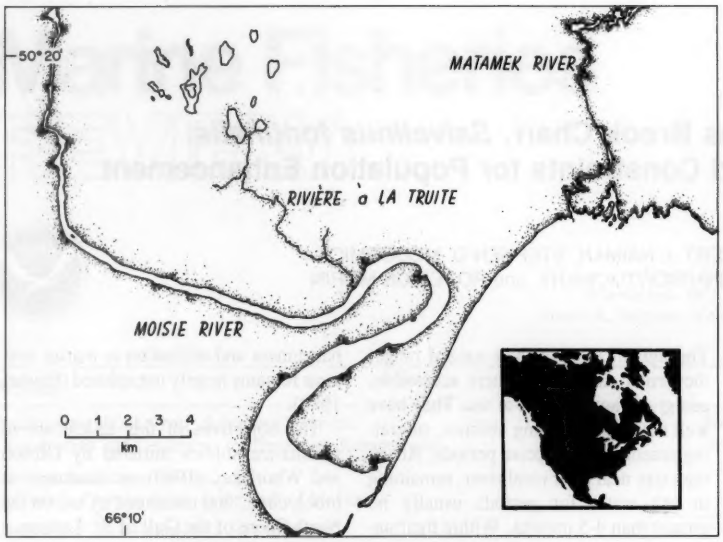


Figure 1.—Location of principal study sites.

Table 1.—Physiochemical characteristics of the study sites.

Parameter	Rivière à la Truite	Matamek River	Moisie River
Stream order	4	6	9
Watershed area (km^2)	36	673	19,871
Mean width (m)	15.6	51.7	208.7
Mean depth (m)	<1.0	1.8	2.5
Mean annual discharge (m^3/sec.)	1.5	13.7	466.1
Substrate	Gravel	Gravel/cobble	Sand/cobble
Temperature range (°C)	0.1-16.0	0.1-22.0	0.1-21.8
Annual degree days (°C/year)	2,000	2,225	2,219
pH range	?	4.8-6.0	6.3-7.1
Alkalinity (as CaCO in mg/L)	?	0-0.5	0-2.1
Forest canopy development	Mostly open	open	open

vestigations of freshwater brook charr in the same watersheds and with information from the literature, provide the basis for evaluating the opportunities for, and constraints upon, the population enhancement of anadromous brook charr.

General Life History

Brook charr are endemic to North America, distributed under natural conditions from the Atlantic provinces south to Long Island, N.Y., in the Appalachian Mountains south to Georgia, west in the upper Mississippi and Great Lakes drainages to Minnesota, and north to Hudson Bay (Scott and Crossman, 1973). They have been introduced successfully throughout the world. Brook charr inhabit well-oxygenated streams and lakes, preferring temperatures below 20°C. They spawn in late summer or autumn, the date varying with latitude and temperature, over gravel beds in headwater streams and rivers. Mature fish may travel a considerable distance upstream to reach the spawning grounds. Unlike lake charr, *Salvelinus namaycush*, and artic charr, *Salvelinus alpinus*, brook charr are short-lived with wild individuals seldom attaining 5 years of age. Sexual maturity is usually reached at age 3, but some individuals may mature at age 2. Maximum size is about 5 kg. In general, brook charr are carnivorous, feeding on a wide range of organisms, depending upon their size and the size of available prey.

Although most populations of brook charr are restricted to fresh water, many coastal rivers in their native territory of northeastern North America contain anadromous brook charr. In northern latitudes, brook charr migrations are characterized by spring emigrations of 2 to 4-year-old fish whose coastal sea residence lasts 2-4 months (White, 1940; Wilder, 1952; Dutil and Power, 1980; Castonguay et al., 1982). In the southern portion of its range, the timing of emigration is more variable, often occurring in the fall (Mullan, 1958).

Assessment of Potential for Enhancement

Initial Experiments

An experiment to induce anadromy in a population of nonanadromous wild brook charr was conducted in 1978 and 1979 near Sept-Iles. This area is a subarctic boreal forest biome (mean annual temperature = 1°C) composed of black spruce, *Picea mariana*; white spruce, *P. glauca*; and balsam fir, *Abies balsamea*. The rivers are ice covered from about November to April. There is a strong freshet in April and May when ~50 percent of the annual discharge occurs. The aquatic growing season is short (~105 days), and the rivers accumulate only about 2,100 degree-days annually (Table 1).

Brook charr from two river systems were chosen for study: An anadromous population from the lower Moisie River and its tributary Rivière à la Truite, and a freshwater population from the Matamek River (Fig. 1). The Matamek River population does not migrate to sea due to a large waterfall, 0.7 km from the ocean, blocking upstream movement to suitable spawning areas, thus precluding anadromous habits. The three rivers differ significantly in physical dimensions but not in most chemical characteristics (Table 1; Naiman et al., 1987) or seasonal timing of environmental events (Naiman, 1982, 1983).

Initially, nearly 1,800 brook charr, age 1+ to 5+, were captured from the Matamek River (identified with serially

numbered Carlin tags if >10 cm fork length (FL) or fin clipped if ≤10 cm FL), transported to the Matamek River estuary from late May to early July, and released (Gibson and Whoriskey, 1980; Whoriskey et al., 1981b). The mean number of days at liberty for different age classes ranged from 63 to 98. Fish were recaptured in autum (late August and September) as they returned to fresh water. Over 2 years, 34.0 percent of the released fish were recaptured. Best returns were in the 2+ and 3+ age classes with 38.0 and 62.1 percent recaptured, respectively. Movement of transplanted fish to other nearby rivers was <1 percent; predation by birds and other fish was not evaluated. All age classes included sea-run brook charr, but the largest percentages of sea-run charr occurred in older and larger fish. Growth was substantially better in sea-run charr than in fish remaining in freshwater (Fig. 2), presumably a function of increased food supply at sea. Tagging severely stunted growth, especially in younger and smaller fish, and probably suppressed anadromy. Nevertheless, tagged sea-run charr grew between 0.8-3.5 percent d^{-1}, which was clearly superior to tagged fish in the freshwater population (0.4 percent day), and they had greater condition factors than their freshwater counterparts. Gonadal maturation was suppressed in sea-run charr compared with fish remaining in fresh water, and there was a significantly larger percentage of female sea-run charr.

These results suggested that an integrated research program could demonstrate the viability of this technique where moderate enhancement of native salmonid production was desired. In 1980 we begun a program investigating movements, feeding, growth, survival, production, reproduction, and physiological adaptation to seawater for wild anadromous brook charr.

Movements

Anadromous northern populations of brook charr tend to leave streams and move to estuaries and coastal marine waters immediately after the peak in the spring freshet (White, 1940; Wilder, 1952; Dutil and Power, 1980; Castonguay et al., 1982). Nevertheless, movements to and from rivers correlate variously with temperature, river discharge (particularly spring floods), lunar cycles, tides, and migrations by other species. In the Moisie River the duration of emigration appears to vary with the pattern of discharge. In 1980, when discharge rose to an early maximum and then declined steadily, the migration was largely completed within 2 weeks; in 1982, when rains caused three secondary discharge peaks following the early June maximum, the migration was extended over 5 weeks (Montgomery et al., 1983). Movements of brook charr into cool, spring-fed creeks of Cape Cod, Mass., seemed to correlate with high summer temperatures of estuarine waters (Mullan, 1958). Migratory activity of brook charr on the Gaspé peninsula, Quebec, correlates with lunar cycles (Castonguay et al., 1982). Migrations of Moisie River charr to coastal waters coincide with simultaneous movements of several other species (Montgomery et al., 1983), suggesting that environmental cues may be similar for all species. Water temperatures in the river and the sea are similar at this time (~8-10°C), reducing the thermal barrier to migration.

Although it is apparent that movements are often rapid and directional, details of migratory behavior are sparse. Our own studies (Montgomery et al.[1]) are typical, involving capture, marking and recapture at a single trap site in the river and at several locations in the estuary. In the Moisie River system, one fish travelled from Rivière à la Truite to the estuary (~15 km) in <2 days, while several others were recaptured in the estuary after <10 days. Anadromous arctic charr and whitefish, *Coregonous* sp., in the coastal Beaufort Sea have a net movement of 3-6 km d^{-1} along the shore (Craig, 1984). Sockeye salmon, *Oncorhynchus nerka*, smolts travel 10-15 km d^{-1} in Babine Lake, B.C., and at much greater rates in rivers (Brett, 1983). It seems unlikely that the trip to the Moisie River estuary would require more than 2 days if movements were strongly directional.

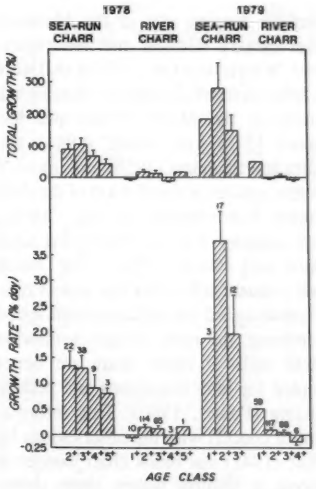


Figure 2.—Growth, expressed as percentage increase of body weight, and mean daily growth rate are shown by age group for tagged brook charr for 1978 and 1979. The 1978 sea-run charr data are calculated from Gibson and Whoriskey (1980). Vertical lines above bars represent one S.E.; numbers are the sample size. Negative values result from handling and tagging stress. Adapted from Whoriskey et al. (1981b).

Data on total distances traversed by migrants are similarly tentative. Records indicate that anadromous brook charr move 30-50 km upriver in the Moisie River (MacGregor, 1973), and Castonguay et al., (1982) sighted schools of anadromous brook charr 48 km upstream from the mouth of the St. Jean River, Quebec. Moore (1975) found migratory Arctic charr a maximum of 50 km upriver on Baffin Island, N.W.T.

Studies indicate that brook charr at sea remain close to their natal rivers. Castonguay et al. (1982) recorded only two strays to adjacent rivers 19 and 45 km from the tagging location in the St. Jean River. During 2 years of experimental tagging only three recaptures (<1 percent of total recaptures) were made away

[1]Montgomery, W. L., R. J. Naiman, S. D. McCormick, F. G. Whoriskey, and G. Black. Biology of anadromous brook charr (*Salvelinus fontinalis*) in the Moisie River, Quebec. Unpubl. manuscr. W. L. Montgomery, Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ 86011.

from the tagging site in the Matamek River estuary (Gibson and Whoriskey, 1980; Whoriskey et al., 1981b). All were recaptured from an intense recreational fishery in the Moisie River and had moved 12-39 km. White (1941) and Smith and Saunders (1958) took most of their recaptures within 5-8 km of the river mouths. Fish generally moved <10 km from tagging sites in Richmond Gulf (Dutil and Power, 1980). The brook trout's square tail with a low aspect ratio is not designed for efficient high speed swimming; the more slender somewhat forked tails of other charr are better adapted for long migrations and pelagic cruising (Power, 1980). This information, in concert with the observations by White (1942) that brook charr wander in schools in shallow waters along shore, suggests that anadromous brook charr remain inshore and close to their river of origin.

As in arctic charr (Craig, 1984) the tendency of brook charr to remain close to home rivers may be influenced by pockets of brackish (5-28‰) and relatively warm (8°-13°C) water along the coastline during the open-water season. This estuarine band varies in width and depth with freshwater input to coastal waters, prevailing winds, and topographic features. In shallow waters (2-3 m) the entire water column is usually brackish; in deeper waters a two-layered system develops, with a lens of surface brackish-water overlying a wedge of colder marine water. A variety of factors (e.g., wind, topography) influence how far the warm, brackish-waters and the brook charr extend seaward, but in most cases we have observed the seaward limit is <10 km (Naiman et al., personal observation).

Feeding

Brook charr are visual, opportunistic predators, whose food habits change in relation to seasonal prey abundance, foraging locality, and effects of agonistic interactions with other fishes (Power, 1980). When brook charr fry emerge from the spawning gravel, they initially feed on minute drifting prey (Williams, 1981; Walsh et al., In press). Subsequently, they feed during daytime along stream edges, consuming increasingly diverse prey as they grow. Cladocera and copedoda constituted 9-31 percent of the food volume in June of emerging brook trout fry from the Matamek River (Williams, 1981). Dipteran larvae, mainly simuliidae and chironomidae, constituted 42-67 percent of the food volume. In July and August the diet shifts to organisms captured at the water surface, including both winged aquatic insects and terrestrial insects (Morin et al., 1982, and unpublished data).

Table 2.—Comparisons of brook charr feeding by the percent volume of taxa in stomach contents for regions of the Matamek River system. Indicated taxa are major components of diet. Streams are presented in increasing order of size. Fish were sampled in June and July.

	Stream				Lake			Estuary
Taxa/group	S[1]	G	T	M5	R	B	M	E
No. fish	28	51	32	111	9	24	29	18
Fork length (cm)	10-15	10-15	10-15	8-18	10-15	15-20	10-20	15
Zooplankton					19			
Insects								
Simuliidae, l[2], p	4	2	14	16				
Chironomidae, l, p	1	6	11			1		
Chaoborus, l					25			
Total Diptera, l, p	5	11	26	19	25	6	7	1
Trichoptera	40	27	12	36	9	4	14	1
Ephemeroptera	4	11	5	5	16	45	36	1
Plecoptera	6	4	14	3			2	
Total insect	55	53	57	63	50	55	59	3
Terrestrial insects	20	35	52	7		1	16	2
Amphipoda								45
Fish						30	5	46

[1]Abbreviations and data sources: S = Sherry Creek, G = Gallienne Creek, T = Tchinicamen (O'Connor, 1974); M5 = Matamek River below 5th Falls (Gibson, 1973); R = Lake MacRae (Carscadden, 1970); B = Lake Bill (O'Connor, 1971); M = Lake Matamek (Saunders, 1969), and E = Matamek River estuary (Whoriskey et al., 1981b).
[2]l = larvae, p = pupae

The diets of juvenile and adult brook charr differ between stream, lake, and estuarine environments (Ricker, 1932a, b; Carlander, 1969). These differences in feeding are reflected in Table 2 based on studies throughout the Matamek River system. Diptera larvae and trichoptera are major components of diets in streams. In 3rd to 5th order streams (Strahler, 1957), brook charr of all sizes consume mainly terrestrial invertebrates at the water surface, particularly in late summer. In large streams such as the Moisie River, brook charr are more piscivorous and depend less upon organisms at the water surface (Montgomery et al.[1]).

Prey consumed by brook charr in saline waters differ in size and probably nutritional value from those in freshwater. Freshwater foods are dominated by small aquatic insect larvae and terrestrial or aquatic insect adults, both of which have considerable refractory exoskeletal materials. In sea water, brook trout feed mainly on fleshy foods such as fishes (particularly sand lance, *Ammodytes* sp.), mysids, and amphipods (Table 2; Whoriskey et al. 1981b; Montgomery et al.[1]). Other dietary studies of brook charr in salt water generally report piscivorous feeding (White, 1942; Greendale and Hunter, 1978; Dutil and Power, 1980). White (1940, 1942) reported that brook charr in the Moser River estuary relied heavily on young eels and saltwater isopods, while amphipods, nereid worms, and freshwater insects constituted the remainder of the diet while those in salt water consumed at least seven species of marine fishes.

Differences between fresh and saltwater feeding also relate to the abundance and seasonal availability of prey. Studies in Quebec indicate that resident fish in rivers feed regularly or heavily only during the 6-week mid-summer period of insect growth and emergence (Gibson and Galbraith, 1975). In contrast, anadromous brook charr have extensive food reserves available throughout their residence in coastal waters. Whoriskey et al. (1981b) found substan-

Table 3.—Comparison of age-weight and growth increments for freshwater and adjacent estuarine populations of brook charr. Weight is shown in grams with instantaneous weight increments in parenthesis.

Location	Lat.	Mean weight and instantaneous weight increment 2+		3+		4+		5+
Richmond Gulf, Quebec[1]	56°N							
River		19	(0.8)	42	(0.5)	71		
Estuary		51	(1.3)	181	(0.8)	399	(0.5)	647
Sept-Iles, Quebec[2]	50°N							
Matamek Lake		22	(1.0)	59	(0.6)	110	(0.5)	188
Matamek River		42	(0.7)	85	(1.0)	221		
Matamek River estuary		66	(0.7)	126	(0.6)	227		
Moisie River estuary				160	(0.8)	346	(0.7)	718
Moser River, Nova Scotia[3]	45°N							
River		62	(0.4)	90	(0.7)	174	(0.6)	309
Estuary		129	(0.7)	249	(0.3)	348	(0.6)	657

[1]Data from Dutil and Power (1980); length converted to weight using, for river fish, a condition factor of 1.1.
[2]Data from Saunders and Power (1970), Whoriskey et al. (1981b), and Montgomery et al. (text footnote 1).
[3]Data from White (1940).

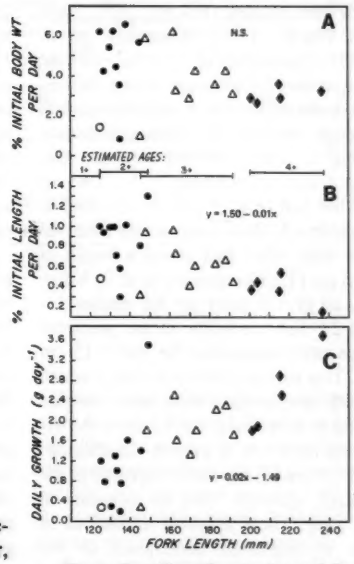


Figure 3.—Growth rate, by weight (A) and length (B), of anadromous brook charr in the Moisie River are presented as a function of initial size and age. Average daily growth (C) is presented as a function of fork length and age. The relationship between growth in weight and fork length (A) is not significant ($P > 0.1$; $r = -0.28$), but the relationships between growth in length (B), daily growth (C), and fork length are significant ($P < 0.05$; $r = -0.58$ and 0.71, respectively). Circles = 1+, dots = 2+, triangles = 3+, and diamonds = 4+.

tial numbers of amphipods and sand lance in the Matamek River estuary, and both foods were available in great abundance in the Moisie River estuary from April to October (Montgomery et al.[1]).

Flesh color of anadromous charr reflects food habits, and may serve as an indicator of perceived quality for human consumption. Increasing age of sea-ranched charr from the Matamek River was accompanied by increasing frequency of yellow or pink flesh and correlated with increased dependence on marine foods (Gibson and Whoriskey, 1980). All 1+ aged fish, 78.3 percent of the 2+, 57.4 percent of the 3+, and 11.8 percent of the 4+ fish had white flesh. In the 2+, 3+, and 4+ age classes the percentages with yellow flesh were, consecutively, 3.1, 7.0, and 5.9; with pink flesh, 14.9, 28.7, and 58.8; and with deep pink flesh, 3.7, 7.0, and 23.5. Larger specimens of anadromous charr from the Moisie River also had colored flesh, although no quantitative data were collected. Arctic charr with red flesh have the greatest market demand in Labrador, followed by charr with pink flesh; charr with white flesh are only used locally (Andrews and Lear, 1969).

Growth and Survival

Brook charr at sea exhibit enhanced growth typical of anadromous salmonids. Table 3 illustrates this pattern by comparing growth in adjacent sea-run and freshwater charr populations. In extensive reviews of the growth of brook charr, Bigelow (1963) and Carlander (1969) reported that sea-run charr attain a maximum weight of about 4.5 kg, no greater than their maximum size reported from freshwater. Unfortunately, no data were available on the age of such fish. In general, growth data are sparse for larger and older brook charr (>1 kg, >6 years of age) and for southern populations, particularly the anadromous populations that once inhabited Long Island, N.Y. and the large New England rivers (Power, 1980). However, instantaneous growth increments between age classes (Table 3) are highest for anadromous brook charr of Hudson Bay and the northern Gulf of St. Lawrence. These regions have shorter growing seasons and colder marine conditions than in the more southerly range of brook charr. The high growth rates in this area, however, may be an artifact of size and age since northern freshwater populations are smaller at any given age than southern populations. An increase in growth rate (due to anadromy) will result in greater growth rates of smaller fish and greater weight increments at any age.

Growth rates were calculated in 1980 for tagged Moisie River brook charr at large for more than 30 days between tagging and recapture, as growth was suppressed during shorter intervals by the tagging procedure (Montgomery et al.[1]). Rates of growth relative to both length and weight declined with increasing initial size and age (Fig. 3B), although absolute rates (g/day) increased significantly ($P > 0.01$) with length (Fig. 3C). These data provide a conservative evaluation of growth since sampling constraints prevented study under fully marine conditions. The daily growth rates from the Moisie River study compare favorably with results from the Matamek River, and are significantly greater than growth rates in fresh water (Saunders and Power, 1970; Gibson, 1973). Tagged brook charr introduced to the Matamek River estuary grew at 0.8 - 3.5 percent/day by weight while tagged brook charr remaining in freshwater grew at 0.4 percent/day (Fig. 2).

Several studies (Wilder, 1952; Dutil and Power, 1980; Whoriskey et al. 1981b; Castonguay et al., 1982) indicate that, at least for some age or size classes, brook charr experience enhanced growth through anadromy by feeding on marine foods. Exceptions to this trend are usually found in younger (1+, 2+) or smaller fish (Fig. 2, 3A, B, C). Moisie River brook charr consistently enter saline water after they attain a length of ≥15 cm FL (Montgomery et al.[1]). Virtually all growth rates for the smaller 1+ and 2+ fish are below means predicted from rates determined for fish ≥15 cm FL. This indicates that size classes which remain in essentially fresh water, despite being in the estuary, fail to attain the expected rapid rate of growth. In addition, fish ≤9 cm FL are rarely captured in the estuary, although they are common in the river. These apparent limitations in size at migration correspond to the known size limitations of brook charr salinity tolerance (discussed below). Considered together, these data indicate that 0+ fish remain in the river, while larger 1+ and older animals move to the estuary and constitute the sea-run component of brook charr in anadromous populations (Montgomery et al.;[1] Whoriskey et al., 1981b).

The survival of anadromous brook charr has not been extensively studied. However, a number of sources suggest that it may be favorable in comparison with freshwater populations. Saunders and Smith (1964) reported that yearling brook charr stocked in estuaries yielded an average return to anglers of 28 percent compared with an average of 13 percent for yearlings and 4 percent for younger charr stocked in the stream. Dutil and Power (1980) recaptured 56 percent of tagged fish during studies in Richmond Gulf, and White (1941) reported returns of 9-40 percent for different size classes of sea-run brook charr in the Moser River, Nova Scotia.

Survival of sea-run charr of the Moisie River was estimated from tagged fish at large at the end of 1980, and recaptured over the following 3 years by anglers (Montgomery et al.[1]). Calculations were made according to Ricker (1975) assuming constant angling pressure between years. Nine hundred sixty-four fish were tagged and released; 557 were 101-150 mm FL, 251 were 151-200 mm FL, and 156 were 201-350 mm FL. The efficiency of the fishery (μ) was estimated to be 22 percent for 101-150 mm fish, 45 percent for 151-200 mm fish, and 31 percent for all sizes. Survival rate(s) between years was estimated to be 31, 20, and 25 percent for the three size groups, respectively.

Estimates of survival for the sea-run population of the Moisie River compare favorably with data from unexploited freshwater charr populations in the Matamek watershed and with seasonal return rates for sea-ranched char in the Matamek estuary. Gibson (1973) estimated minimum survival to be 46 and 16 percent based on recovery of brook charr marked in a previous year at two sites in the lower Matamek River. The lower estimate (16 percent) was attributed to a greater proportion of tagged yearlings which were thought to incur higher mortality during winter. O'Connor and Power (1976) estimated survival from year-class structures of four stream populations of brook charr in the Matamek watershed. Survival rates between successive year classes of charr aged 1 year and older ranged between 17 and 37 percent. In our induced anadromy experiments, minimum recovery rates over 2 years were 29 and 40 percent for charr released in the Matamek River estuary (Gibson and Whoriskey, 1980; Whoriskey et al., 1981b).

Production

The growth attained in our induced anadromy project is particularly interesting since growth and production in the Matamek River drainage network are among the lowest reported throughout the geographic range of brook charr (Saunders and Power, 1970; O'Connor and Power, 1976; Power, 1980). Charr production in lakes of the Matamek River watershed ranges from only 0.5 to 2.2 kg/ha/year (Carscadden, 1970; Saunders and Power, 1970; O'Connor and Power, 1973) and in streams leading into Matamek Lake it is 14.5-66.4 kg/ha/year (O'Connor and Power, 1976). The growth of charr in the Matamek River is most rapid during the first 2 years of life, accounting for 70-90 percent of total population production.

Despite the apparent abundance of flowing waters in northern watersheds, only a small fraction of those waters actually contribute to fish production, making the marine phase of brook charr life history even more significant. Fish are absent from first and second order streams and sparse in third order streams on the North Shore of the Gulf of St. Lawrence (Naiman et al., 1987; Morin and Naiman, unpubl. data). These streams are subject to nearly complete freezing in winter and experience substantial variations in flow and temperature during summer. First to third order streams constitute 23 percent of the total surface area of streams in the Moisie River system (Naiman, 1983), but have negligible fish production. Significant fish production in the Matamek system occurs only in streams ≥4th order (O'Connor and Power, 1976). These constitute 70 percent of the stream surface area in that system, but even this is an overestimate of productive habitat. Given the depth distribution and habitat requirements of fry and yearling, significant charr production is possible in <40 percent of the total lotic surface area. In short, these northern river systems cannot normally support highly productive salmonid populations; anadromous populations circumvent to some degree the limitations of food, space, and temperature (Gibson and Galbraith, 1975; Gibson et al., 1976; O'Connor and Power, 1976; Walsh et al., In press) during critical mid-summer periods by moving to coastal areas.

To evaluate the viability of an enhancement program, it is essential to know, first, the biological productivity of anadromous brook charr populations and second, how much of that production can be successfully harvested. Neither determination has been made for an anadromous brook charr population. Nevertheless, given the observed growth rates of brook charr aged 2+ to 7+ in the Moisie River estuary, production of those year classes in freshwater populations (e.g., O'Connor and Power, 1976) could approximately double if they moved to sea and incurred similar mortality. Such an estimate is based only on the difference between sea and freshwater growth and

does not include possible increases in recruitment by anadromous charr due to increased growth, fecundity, and spawning frequency. Measures of yield from northern commercial and native fisheries on anadromous populations of Atlantic salmon, Arctic charr, brook charr, and whitefish (Power, 1966, 1980; Power and LeJeune, 1976; MacCrimmon and Gots, 1980) also suggest that this estimate of potential for enhanced production is conservative.

Table 4.—Age-specific maturity for Matamek River brook charr from the Second and Fifth Falls, and from the Moisie River. Values in percent; M = male, F = female. Numbers in parentheses are sample sizes.

	Age											
	1+		2+		3+		4+					
Site	M	F	M	F	M	F	M	F				
Matamek River[1]												
Second Falls		0 (5)	29 (17)	29 (17)	73 (26)	91 (32)	50 (12)	100 (6)				
Fifth Falls	41 (49)	0 (29)	37 (43)	81 (37)	69 (13)	100 (24)		88 (8)				
Moisie River[2]												
Anadromous only	20 (10)	0 (4)	50 (20)	52 (25)	80 (5)	72 (18)	100 (3)	100 (5)				
Freshwater and anadromous	10 (197)	3 (163)	33 (93)	27 (94)	67 (6)	67 (21)	100 (3)	100 (5)				

[1]From Gibson et al. (1976).
[2]From Montgomery et al. (text footnote 1).

Reproduction

Despite extensive observations, we were unable to detect any significant differences in choice of spawning site, reproductive behavior, fertility, early ontogeny, or early life history between anadromous and nonanadromous stocks of brook charr (unpublished data). Power (1980) has described these reproductive aspects in detail. Our discussion here centers around maturation schedules, fecundity, and life history strategies.

While age is often reported as a correlate of maturation, other factors also influence its onset. Under laboratory or hatchery conditions, size is a more important determinant of maturation in brook charr than either age or growth rate, explaining 97-99 percent of the variation in maturation (McCormick and Naiman, 1985b). Under accelerated growing conditions, brook charr mature and spawn in their first autumn, at an age of 10 months and a weight of 60 g (Carlson and Hale, 1973; McCormick and Naiman, unpubl. data). Other physiological features (e.g., nutritional state and health) also influence time of maturation. Schedules of maturation normally differ between sexes, with the proportion of mature males greater at small sizes than that of mature females (Carlson and Hale, 1973; Power, 1980; McCormick and Naiman, 1985b). This difference is characteristic of many fishes and other poikilothermic vertebrates, and may relate to the nature of mating systems and to differential energetic investment in reproductive products (Bell, 1980).

Brook charr mature over a wide range of sizes and ages. This probably results from genetic differences between stocks combined with phenotypic responses to environmental variation. Environmental factors such as food, habitat, population density, temperature, and salinity, may act indirectly (through size or growth rate), or directly, on the onset of maturation. In highly productive streams, brook charr mature as early as 1+ or 2+ years of age; in northern or unproductive rivers maturation begins at ages >3+ (Power, 1980). Relatively late maturation also characterizes anadromous brook charr (White, 1940; Castonguay et al., 1982), and anadromous and experimentally transplanted brook charr show signs of delayed gonadal development upon reentering freshwater (White, 1940; Whoriskey et al. 1981b). Dutil and Power (1980) observed that final ripening of gonads of anadromous brook charr occurs in freshwater.

Reproduction by anadromous brook charr in the Moisie River system is largely delayed until the fish attain age 2+ and return to spawning tributaries at lengths >15 cm FL (Montgomery et al.[1]). Females lagged behind males in attaining maturity (Table 4). Similar patterns were observed in Moisie River fish that had not been tagged. It is surprising that maturity schedules for tagged fish from the Moisie River are comparable to those for tagged Matamek River charr (Gibson et al., 1976), as maturation was much lower in tagged Matamek River fish of the same age (Whoriskey et al., 1981b). The only clear difference between the two populations was that Matamek River females tended to lead males in percentage maturation at ages greater than 1+ (Table 4).

Power (1980) found little difference in interpopulation weight-specific fecundity of brook charr. Only the anadromous stock from the Koksoak River, Ungava Bay, Quebec, seems to increase fecundity more rapidly than other populations, and that only occurs at lengths >40 cm FL. However, when slopes of fecundity-weight regressions are compared for freshwater and anadromous brook charr in the same region, the slopes for Moisie River fish (2.8 in 1972, in MacGregor, 1973; 3.0 in 1980, Montgomery et al.[1]) exceed those reported for fish from lakes and streams in the Matamek River drainage (1.7-2.4; Fig. 4). Thus, anadromous charr may gain an advantage in terms of increased fecundity beyond that predicted from simple increases in body size (Fig. 4).

Freshwater brook charr in northern regions have different life history strategies than anadromous stocks (Power, 1980). In northern streams the fish grow slowly, not all fish mature at the same age, and there is the possibility of multiple spawning so that the reproductive potential of a year class is spread over more than one year (Fig. 5A). Sex ratios shift in favor of females in the older age groups. A few males are long lived, and the oldest fish in a population may often be a large male (Power, 1980).

With the addition of a migratory phase to the life cycle and a separation of spawning and nursery areas from feedings grounds, a life cycle of the type in Fig. 5B is found in anadromous populations. Anadromous migration provides more living space and results in better growth, possible lower mortality, larger fish, and better fecundity. Annual spawning usually occurs once maturity is

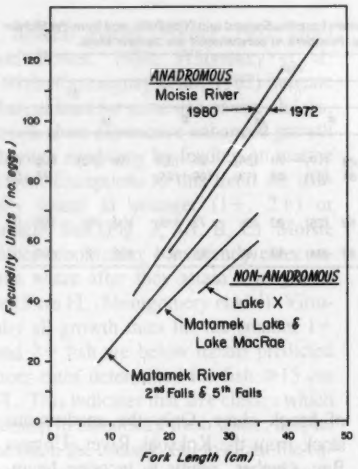


Figure 4.—Size-related increases in fecundity for Quebec brook charr. All intercepts of linear regression equations for fecundity on FL have been adjusted to zero. Projection of lines on abcissa gives the size range of fish used for regression. Data sources are: Moisie River, 1972 (MacGregor, 1973); Moisie River, 1980 (Montgomery et al., text footnote 1); Lake X and Lake MacRae in Matamek River watershed (O'Connor, 1971); and Matamek River (Gibson et al., 1976).

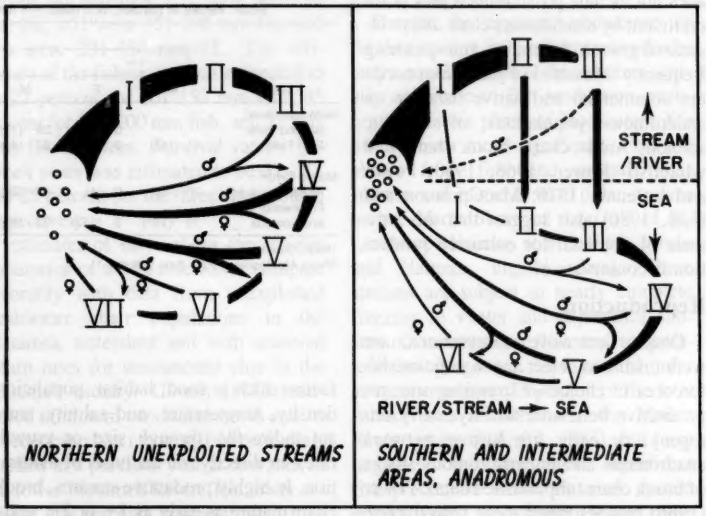


Figure 5.—The life history strategy of nonanadromous brook charr in northern streams is contrasted with that of an anadromous stock in the same area. Adapted from Power (1980).

attained. Multiple spawning is normal so that the reproductive potential of a year class is spread over 2-3 years. In combination, these factors make anadromy an important alternate life history strategy for brook charr with oceanic access.

Physiological Adaptation to Seawater

Movement of brook charr from fresh water to salt water requires not only a behavioral (migratory) impetus but also a physiological tolerance to salinity. The latter depends primarily on the ability to regulate plasma ions in a hyperosmotic medium. For a variety of teleosts, including salmonids, salinity tolerance and hypoosmoregulatory ability have been shown to change as a function of size and life history stage (Parry, 1958; Conte and Wagner, 1965; Conte et al., 1966; Nordlie et al., 1982).

McCormick and Naiman (1984b) demonstrated that survival of brook charr between 6.0 and 32.0 cm FL in 32‰ seawater was size dependent ($r^2 = 0.77$), as was the ability to regulate plasma ions (Na^+, Cl^-, K^+, Mg^{+2}) and plasma osmolarity (Fig. 6). Age, by itself, had no significant influence on seawater survival of brook charr. Size dependent hypoosmoregulation may be the result of more favorable surface area-to-volume ratios in larger fish. Although seawater survival increases throughout all sizes tested (6.0-32.0 cm FL), fish >15 cm FL achieved a near-maximum rate of survival.

In addition to ontogenetic changes associated with size, hypoosmoregulation is also affected by gonadal maturation of males (McCormick and Naiman, 1985a). Seawater survival of mature males is lower than that of mature females or immature fish of similar size in spring, summer, and autumn (mature brook charr were not tested in winter). Furthermore, mean survival time of mature males in seawater is reduced by >50 percent in autumn during the normal spawning period. The ability of mature male brook charr to regulate plasma ions (Cl^- and

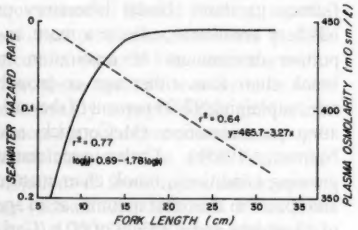


Figure 6.—Size dependent survival after 20 days (—) and plasma osmolarity after 4 days (—) of exposure to 32‰ seawater. Seawater hazard rate is a measure of the probability of survival (number of deaths/days at risk), with survival rate increasing as hazard rate approaches zero. Data originally presented in McCormick and Naiman (1984b).

Mg^{+2}) and osmolarity in seawater during autumn is significantly reduced relative to that of mature females. Mature females and immature brook charr of both sexes exhibit no such decline in autumnal seawater survival.

The decreased salinity tolerance of males during gonadal maturation signi-

Table 5.—Phylogenic comparison of size-dependent salinity tolerance and seaward migration in salmonids.

Species	Salinity tolerance: Salinity (ppt)	Salinity tolerance: Method of acclimation	Duration (days)	Size at 75% survival (cm)	Size at seaward migration (cm)	References
Oncorhynchus						
Pink salmon	32	Direct	>14	<6.0	2.5-4.0	(1, 2)
Chum salmon	32	Direct	>14	<6.0	3.2-7.0	(1, 2)
Chinook salmon	30	Direct	30	6.5	6.0-10.0	(3, 4)
	30	Gradual	30	4.2		
Coho salmon	30	Direct	30	7.0	10.0-11.0	(5, 4)
Salmo						
Atlantic salmon	29	Direct	44	13.8	12.7-15.2	(6, 2)
Steelhead trout	30	Direct	30	16.0	15.0-20.0	(7, 8)
Salvelinus						
Brook charr	32	Gradual	20	19.0	15.0-18.0	(9, 10)

[1]1 = Weisbart, 1968; 2 = Scott and Crossman, 1973; 3 = Wagner et al., 1969; 4 = Healey, 1980; 5 = Conte et al., 1966; 6 = Johnston and Saunders, 1981; 7 = Conte and Wagner, 1965; 8 = Wagner et al., 1963; 9 = McCormick and Naiman, 1984b; 10 = Montgomery et al., text footnote 1.

fies a potential negative effect on males in enhancement programs. In fact, poor seawater survival (or preference) may explain the existence of greater female: male sex ratios in most populations of anadromous and sea-ranched brook charr (White, 1940; Wilder, 1952; Whoriskey et al., 1981b; Castonguay et al., 1982; Montgomery et al.[1]).

The influence of seasonal daylengths on developmental events has a substantial impact on the osmoregulatory physiology of salmonids. Photoperiod entrains the timing of maturation in salmonids (Billard et al., 1978; McCormick and Naiman, 1985b) and will therefore influence seawater survival of brook charr through male maturation (McCormick and Naiman, 1985a). In Atlantic salmon, *Salmo salar*, and Pacific salmon, *Oncorhynchus* spp., the transition from resident parr to migratory smolt is cued by photoperiod, presumably acting through the hypothalmus-pituitary system. Known as smoltification, this process includes seasonal (usually springtime) changes in appearance, behavior, morphology, and body composition, and increases in gill Na^+, K^+-ATPase activity and hypoosmoregulatory ability (see reviews by Hoar, 1976; Folmar and Dickhoff, 1980; Wedemeyer et al., 1980; and McCormick and Saunders, In press). Some of these changes may be mediated by surges in plasma thyroxine (Folmar and Dickhoff, 1980). Anadromous brook charr often possess the silver coloration and migratory behavior characteristic of salmon smolts (White, 1940; Wilder, 1952), but silvering of brook charr does not indicate imminent seawater entry (Black, 1981). Unlike smolting salmonids, brook charr do not display photoperiod-induced increases in gill Na^+, K^+-ATPase activity or hypoosmoregulatory ability (McCormick and Naiman, 1984a, b). Furthermore, there are no significant differences ($P > 0.05$) in gill Na^+, K^+-ATPase activities or plasma thyroxine levels between anadromous and nonanadromous brook charr from adjacent rivers (McCormick et al., 1985). From these and other results we have concluded that physiological changes preparatory for seawater entry that are observed in smolting salmonids are undeveloped in brook charr.

While photoperiod appears to affect salinity tolerance of brook charr only through maturation, other environmental factors will have direct impact. Though largely unexplored in brook charr, the interaction of temperature and salinity affects ion transport in other salmonids (Rao, 1969). Ionic equilibrium of presmolt Atlantic salmon after seawater exposure was achieved more quickly at an acclimation temperature of 10°C than at 1.5°C (Virtanen and Oikari, 1984). Poor osmoregulatory capacity at low temperature could explain high mortality of brook charr and Arctic charr overwintered in seawater net pens (Saunders et al., 1975; Wandsvik and Jobling, 1982).

Method of seawater acclimation also affects survival. Brook charr acclimated for 1-2 weeks at intermediate salinities (10-25‰) before transfer to 32‰ sea water had only 18 percent mortality after 20 days vs. 85 percent mortality for those transferred directly (McCormick, unpubl. data). This is in agreement with our observations that brook charr may spend up to a month in an estuary before migrating to sea (Montgomery et al.[1]), and that at estuarine sites characterized by high salinity, gill Na^+, K^+-ATPase activity and hypoosmoregulatory ability are elevated (McCormick et al., 1985). In addition, relatively small increases in salinity (e.g., 28‰ vs. 32‰) can have dramatic effects on salmonid survival (Jackson, 1981).

Because the decision to use brook charr in enhancement programs for anadromous salmonids will undoubtedly be made relative to the use of other salmonids, it is instructive to compare the relative salinity tolerances of salmonids (Table 5). Size dependent hypoosmoregulatory abilty is a common feature of all salmonids (Parry, 1958; Conte and Wagner, 1965; Conte et al., 1966; Weisbart, 1968; Farmer et al., 1978). As might be expected, the size at which salinity tolerance is achieved is similar to that at which normal seaward migration occurs (Table 5). Species of the genus *Oncorhynchus* have relatively greater salinity tolerance at any size than *Salmo* sp. (e.g., Atlantic salmon and rainbow trout), followed by *Salvelinus* sp. (see Rounsefell, 1958). We have hypothesized that greater exploitation of the sea has been accompanied by adaptations to decrease the impact of size dependent ion transport in a hyperosmotic environment (McCormick and Naiman, 1984b). Other things being equal, enhancement of anadromous brook charr will require longer rearing in fresh water so that a larger body size is achieved before introduction to seawater.

Exploitation of Anadromous Brook Charr

For at least 5,000 years northern peoples have fished for brook charr (MacCrimmon and Gots, 1980). Nevertheless, throughout their native range, there are only four historical records of anadro-

mous brook charr being harvested commercially. In the 1800's they were netted in the ocean near the Magdalen Islands, Quebec, during summer and pickled for export to the West Indies where, if in choice condition, they brought a higher price than Atlantic salmon (Perley, 1852; Lanman, 1873). Anadromous brook charr were also commercially exploited in Ungava Bay, Quebec, in Laborador by the Hudson's Bay Company in the 19th Century (G. Power[2]) and in Richmond Gulf, Quebec, between 1962 and 1964 (Power and LeJeune, 1976). On the Koksoak River, Quebec, the native harvest has been estimated at 15,500 kg/year[3]. Anadromous charr currently are netted for local consumption wherever they are present in sufficient numbers, but they are not generally numerous enough to be of widescale commercial importance, since most natural populations consist of only a few thousand fish.

The main economic value of anadromous brook charr probably lies in providing recreation. In contrast to occasional commercial and native exploitation, anadromous charr have consistently been a favorite with anglers, notably in New England and the Maritime region of Canada (Perley, 1852; Bigelow, 1963). In the past, much of the recreational angling in eastern Canada and the northeastern United States was provided by Atlantic salmon. However, the worldwide catch had declined 42 percent between 1967 and 1982 despite a severalfold increase in fishing effort (RASA, 1983), and the decline continues. Some 41 percent of coastal streams in New Brunswick have sea-run charr in sufficient quantities to provide a sport fishery. In Newfoundland, anadromous brook charr are second only to Atlantic salmon as a quarry for anglers (Scott and Crossman, 1964). Moreover, in recent years, about 21.7 million brook charr have been distributed annually from government hatcheries in the United States and Canada to meet public demand for recreational fishing (MacCrimmon and Gots, 1980). In coastal areas the angling effort for anadromous brook charr can be substantial. For example, in the Moisie River, Quebec, 18 percent of the fish tagged as part of our migration study in this remote area were returned by anglers (Montgomery et al.[1]).

Table 6.—Perceived positive and negative aspects associated with the enhancement of anadromy in brook charr.

Parameter	Positive aspects	Negative aspects
Life history traits	1. Short, synchronized migrations 2. Remain in coastal areas 3. Rapid growth at sea 4. Multiple spawnings after age 2+ 5. Minimum straying	1. Must be close to seawater for anadromy 2. Requires overwinter habitat in northern rivers 3. 2-3 yrs before migration in northern latitudes
Physiology	1. Tolerance to low pH and low temperatures 2. Ability to enter brackish water at a small size	1. Difficulty adapting to full-strength seawater until 15-18 cm FL 2. Poor salinity tolerance of mature males
Genetics	1. Genetically plastic throughout range; possibility for selective breeding	1. None known
Economics	1. Low costs for fishery development and maintenance 2. Potentially high yield for recreational fishery 3. High quality fish 4. Improved social situation for rural communities 5. Available to anglers with average incomes	1. Typical resource management problems associated with anadromous fisheries

Summary

We suggest that anadromous brook charr and other members of the genus *Salvelinus*, have inherent traits making them reasonable candidates for enhancement programs (Table 6). In northern latitudes they make short, synchronized migrations to coastal areas during the ice-free season, they remain close to shore where they are not subject to interception by foreign vessels, they undergo rapid growth while at sea, they begin reproduction at about 2 years and reproduce every 1-2 years thereafter, and they exhibit the strong homing ability characteristic of other salmonids (Fig. 7). Brook charr are able to tolerate a wide variety of environmental conditions including low food levels and low water temperatures, and are more resistant to low pH than other salmonids (Muniz and Grarde, 1974). Moreover, they appear to have population dependent differences in life histories suggesting a genetic plasticity which offers substantial opportunities for selective breeding. These positive factors are essential for potential use of this species for enhancement and for commercial sea ranching efforts.

There are, however, some negative aspects to consider (Table 6). First, brook charr must be close to seawater to induce anadromy. Apparently they do not make long (>75 km) migrations to sea. They require overwintering habitat in fresh water and rearing habitat for 2-3 years before migration from northern rivers. Second, brook charr have difficulty in adapting to full-strength seawater before reaching a size of 15 cm FL. Three factors appear to exert the strongest limitations on the salinity tolerance of brook charr: 1) Size is of primary importance; brook charr ≤15 cm FL will probably not survive well at salinities greater than 25‰. 2) Gradual acclimation at intermediate salinities eases osmotic stress and increases survival. 3) The negative effect of male maturation on salinity tolerance is likely to preclude introduction of mature fish into seawater, particularity in autumn. Spring releases of juveniles may circumvent some or all problems associated with poor seawater survival of mature males. Eventually, development of late-maturing stocks, sex control, or sterilization may prove advantageous. The greater degree of size dependent salinity tolerance in brook charr requires a longer freshwater rearing phase than for other anadromous salmonids. Since freshwater

[2]Geoff Power, Department of Biology, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada. Personal commun.

[3]N.Q.I.A. 1976. Research to establish present levels of harvesting by native peoples of northern Quebec. Part II. A report on the harvests by the Inuit of northern Quebec. 230 p.

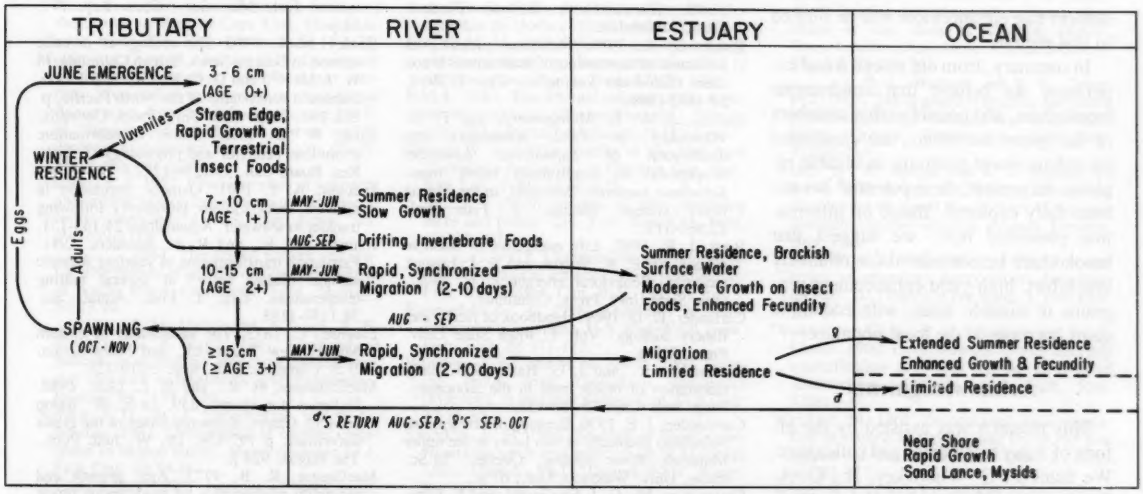


Figure 7.—The life history of anadromous brook charr studied by our group near Sept-Iles, Quebec, is summarized. See text for explanation.

rearing is often limiting or costly, this is an important consideration in choosing a species for enhancement. It will be necessary to judge the limitations of salinity tolerance in brook charr against other merits for enhancing salmonid production to properly evaluate their potential. Finally, there are the typical resource management problems associated with anadromous fisheries where fish often use habitats under the jurisdiction of several agencies with different management priorities.

Considering both the positive and negative factors, we recommend that anadromous brook charr be used in local enhancement programs where the objective is to provide a high quality recreational fishery. This may include habitat improvement, supplemental stocking to aid previously overexploited populations, improved management to protect the seasonal movements and reproduction of the population, or the development of a hatchery (or genetic) program to exploit life history characteristics that appear useful for population enhancement. For instance, the initial experiments with inducing anadromy (sea ranching) demonstrated the potential for using brook charr in a moderate effort, high yield enhancement technique (Gibson and Whoriskey 1980; Whoriskey et al. 1981b). However, certain aspects can be modified to improve the production and return of anadromous charr. These modifications are applicable to both population enhancement for the purpose of expanding fisheries potential and to commercial sea ranching.

Survival could be improved by gradual acclimation to seawater, releasing fish only during the period of natural migration to sea, using large estuaries with the proper geomorphology (mixed vs. stratified water, etc.), and using fish in good condition. Harvesting fish could be improved by recapture at a counting fence, or some other structure that concentrates individuals soon after reentry into fresh water in autumn. Growth rates at sea could possibly be enhanced by choosing marine sites having physical attributes to insure abundant food resources and by selective breeding of an anadromous stock. Although we are not aware of any negative genetic aspects, genetics could have major consequences and should be considered. At this point we recommend that enhancement be limited to the use of local stocks. Two basic enhancement strategies are habitat restoration of streams where anadromous brook charr once flourished and use of local native populations for hatchery stock to supplement existing populations.

However, several characteristics of brook charr will, in our judgment, make them a relatively poor choice for commercial net pen culture in high salinity. Relative to other species, brook charr require a longer rearing period in fresh water prior to entrance into seawater. Gradual acclimation to seawater in commercial net pen culture would in many cases be costly or infeasible. The poor performance of mature males in sea water and the relatively small size of maturation in both sexes will limit the period of seawater culture. These factors will work against the economic viability of net pen culture.

One final consideration is that in the southern part of the brook charr's range (i.e., near Cape Cod, Massachusetts), faster growth could reduce the length of freshwater residence. However, in those areas they would face increased numbers of competitors, warmer marine waters which they do not tolerate well, and habitat degradation. North of Cape Cod, conditions are more favorable for enhancement of anadromous brook charr. We

suspect that enhancement will be limited to that region.

In summary, from our research and experience we believe that anadromous brook charr, and possibly other members of the genus *Salvelinus*, are candidates for enhancement programs in suitable regions. At present, their potential has not been fully explored. Based on information presented here, we suggest that brook charr be considered for relatively low-effort, high-yield enhancement programs in suitable areas, with economic gains accruing to the local populace.

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Commercial Fishing for Gulf Butterfish, *Peprilus burti*, in the Gulf of Mexico

MICHAEL VECCHIONE

Introduction

The decline of oil prices during the 1980's has caused serious problems for the petrochemical-based economy of southwestern Louisiana. One result of the high unemployment rates (>14 percent) in this area has been that many unemployed workers have turned to commercial fishing, especially shrimping, as a source of income. This, in turn, has increased competition for resources in the shrimping industry, which was already highly competitive before these times of economic hardship.

In addition to shrimp, many other fisheries resources are available in the Gulf of Mexico. Some have not been harvested in the past, even though there are indications that they may be abundant and marketable. One of the most promising of these latent fishery resources is the gulf butterfish, *Peprilus burti*.

A commercial fishery exists in the Middle Atlantic Bight for a very similar species, the Atlantic butterfish, *Peprilus triacanthus* (Murawski and Waring, 1979). This butterfishing industry has included both domestic fishermen and the distant-water fleets of foreign nations, although foreign fleets have not had a directed butterfish allocation since 1979 (G. T. Waring, NMFS, Woods Hole, Mass., personal commun., 1987). Most of the catch, which peaked at 19,454 metric tons (t) in 1979 (Gledhill[1]), is marketed overseas, primarily in Japan. Landings of Atlantic butterfish have fluctuated considerably from year to year for reasons which are not well understood (Murawski et al., 1978). Thus, demand for butterfish cannot always be met by the U.S. East Coast butterfish industry.

Exploratory trawling by the National Marine Fisheries Service (NMFS) has indicated that gulf butterfish are abundant and the stock could sustain an annual harvest of as much as 50,000 t (Gledhill[1]). Furthermore, butterfish of marketable size have been taken primarily in deep water on the outer continental shelf, offshore of the fishing grounds for both brown shrimp and white shrimp. Therefore, a butterfish industry could develop in the Gulf of Mexico without increasing competition on traditional fishing grounds.

Before local fishermen can be expected to invest in the conversion necessary for deep-water trawling, there must be a clear indication that such expenses are economically justifiable. Research trawling by NMFS using established methods such as random or fixed site selection cannot fully address the question of whether a commercial butterfishing operation can be economically successful. Therefore, the Lake Charles Harbor and Terminal District, together with McNeese State University, arranged for a New England firm experienced in catching and marketing butterfish to conduct exploratory operations in the Gulf of Mexico.

The objectives of this project were to 1) examine the methods used in commercial butterfishing, 2) determine the availability of gulf butterfish using commercial methods, and 3) determine whether the resource could be marketed successfully.

Methods

Two freezer-trawlers[2] rigged for stern trawling were committed to this project. Technical specifications of these vessels, the F/V *Huntress* and the F/V *Old Colony*, are summarized in Table 1. Both vessels fished large nets (Table 2) which were manipulated through a ramp in the stern. The nets were rigged with louvered steel doors (Bison doors from Great Britain) and were towed on a double

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ABSTRACT—This study was done to determine if gulf butterfish, Peprilus burti, *is a reasonable alternative to traditional resources for commercial fishermen in the northern Gulf of Mexico. A commercial fishing firm which has successfully fished for and marketed butterfish off New England was contracted to conduct operations in the Gulf of Mexico. Two of the firm's stern-rigged freezer trawlers fished for 1 month (May-June 1986) on the outer continental shelf off Mississippi. Both vessels caught gulf butterfish in quantities and sizes that were commercially valuable, and the fish were successfully marketed in Japan. Data on catch rates, unloading and shipping costs, and marketing results are presented.*

[1]Gledhill, C. T. 1986. A preliminary estimate of gulf butterfish (*Peprilus burti*) MSY and economic yield. Southeast Fisheries Center Mississippi Laboratories, National Marine Fisheries Service, NOAA, Pascagoula, Miss. Unpubl. rep.

[2]Mention of any trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Technical specifications of fishing vessels.

F/V Old Colony	
Length overall:	132 feet
Width:	28 feet
Draft:	15 feet
Main Engine:	1,500 HP
Generator capacity:	370 KW
Electronics:	Chromascope color fish finder Loran C Single-sideband, VHF, CB radios Radar
Refrigeration:	2 ea. 100 KW compressors 4 contact freezers, freezing temp. −40°C. Refrigerated hold, temp. −30°C.
Freezing capacity:	34 t/24 hours
Holding capacity:	150 t
Processing area:	Enclosed, cooled
Construction:	Steel, sterntrawler, shelterdecked
F/V Huntress	
Length overall:	100 feet
Width:	26 feet
Draft:	12 feet
Main Engine:	700 HP
Generator capacity:	310 KW
Electronics:	Chromascope color fish finder Loran C Single-sideband, VHF, CB radios Radar
Refrigeration:	2 ea. 100 KW compressors 3 contact freezers, freezing temp. −40°C. Refrigerated hold, temp. −30°C.
Freezing capacity:	27 t/24 hours
Holding capacity:	65 t
Processing area:	Enclosed, cooled
Construction:	Steel, sterntrawler

Table 2.—Net Specifications.

Shuman trawl
170 foot sweep, 15 foot rise
32" mesh in face, grading through 12" and 8" to 4" in cod end
Ground cable, 75 fathoms
Bison doors
Whiting trawl
140 foot sweep, ca. 12 foot rise
Mesh similar to above, but with $3\frac{1}{2}$" cod-end liner
Ground cable, 75 fathoms
Bison doors
Roller trawl
60 foot sweep, 9 foot rise
4" mesh throughout, $3\frac{1}{2}$" cod-end liner
Ground cable, 25 fathoms
Bison doors
24" diameter rubber rollers along footrope

warp with a 3:1 scope. Long ground cables of rope-wrapped wire connected the doors to the nets. Duration of tows varied but was generally within the range of from 30 minutes to 2 hours. When not being towed, the nets were stowed on large hydraulic net drums, of which each vessel had two.

Each vessel made three trips of 5-10 days duration during the 30-day project period, returning to port for 2-4 days between trips for unloading and repairs. I accompanied the *Huntress* throughout the period of the project and recorded data on operations and catch characteristics. An observer from NMFS recorded similar data on the *Old Colony* on two of its three trips. Therefore, the data are somewhat more complete on the *Huntress'* operations and catch. Towing sites were selected by the captains of the vessels based on experience and chromascope traces. Whereas bottom depths at towing sites ranged from 35 to 223 m (19-121 fathoms), most tows were in the 129-185 m (70-100 fathoms) depth range along the edge of the continental shelf (Fig. 1). Towing direction generally followed depth contours. Although fishing was conducted mostly during daylight hours, some tows were made before sunrise and after sunset.

Both vessels were fitted with movable stanchions in which boards could be fitted to form corrals of various sizes on deck. After each tow, the catch was winched up the stern ramp, and then dumped in a corral. After removal of large sharks, rays, and other fishes, deck hoses were used to wash the catch into a sump from which a conveyor belt lifted the catch to a sorting platform. If the catch was mostly butterfish, other species were culled at the sorting platform and the butterfish were fed into a grading machine which removed unmarketably small fish based on body thickness. If the percentage of butterfish in the catch was low, they were picked out manually at the sorting platform. In either case, the butterfish were then passed to an enclosed, cooled processing area where they were boxed whole (not graded by size) in 11.25 kg boxes and then frozen on contact-plate freezers. Once completely frozen, the boxes were transferred to a freezer storage hold.

Composition of the catch was determined by sampling the catch as soon as it was dumped on deck. A standard 30 kg sample was removed and examined in detail. This sampling method did not include the sharks and other large fishes, but these were subjectively noted in the field log. All butterfish in the sample were counted and their aggregate weight was determined. Either 25 or 50 butterfish were selected arbitrarily and measured (standard length, SL) from each sample. Some butterfish were selected arbitrarily as representative of the entire length range and weighed to construct a length-weight regression. Parameters presented below include 1) catch rate (kilograms of butterfish boxed and frozen per hour of towing), 2) percentage of the sample which was butterfish, 3) average weight of individual butterfish in the sample, 4) median length of measured butterfish in the sample, 5) length-frequency distribution of butterfish in the sample, 6) length of the largest butterfish in the sample, and 7) the relationship between standard length and weight for butterfish in the study area at this time of year. Observations on bycatch composition (species, total number, and aggregate weight) were recorded for most samples.

Results

Catch Characteristics

Gear Comparisons

Although it might be expected that the different types of nets would vary in catch characteristics, none of the differences among the three types of nets in the parameters listed above were statistically significant.

Catch Rate

The amount of product frozen per hour on F/V *Huntress* differed significantly both among trips and among days (based on analysis of variance (ANOVA), with statistical significance defined as <5 percent probability that the pattern observed could be random). Catch rate on the *Huntress* averaged 367 kg/hour on the first trip, then decreased to average 323 kg/hour on the second trip. Average catch was substantially higher on the third trip (1,137 kg/hour); This may be a result of significant (based on ANOVA, d.f.=111,2; F=19.9; $P<0.01$) differences in the depth fished among the three trips. Whereas the largest catches were consistently taken at depths of 155-225 m (Fig. 2), the average depth fished on the

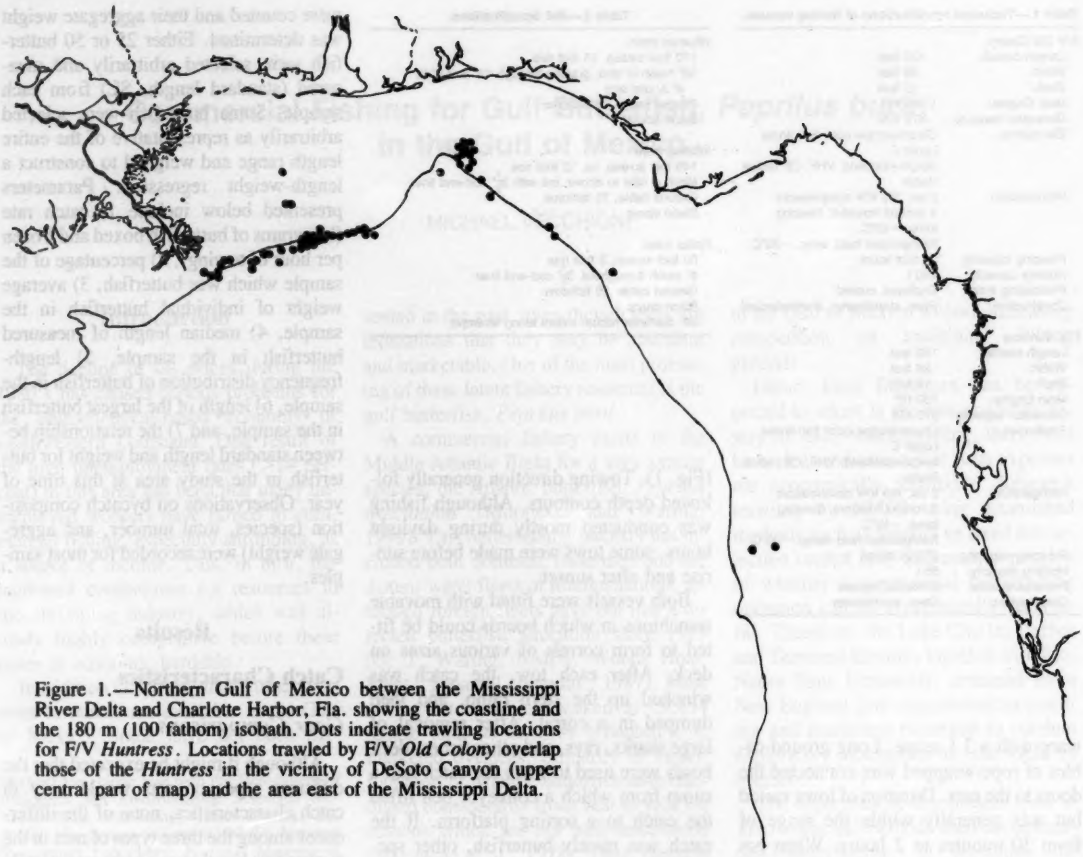

Figure 1.—Northern Gulf of Mexico between the Mississippi River Delta and Charlotte Harbor, Fla. showing the coastline and the 180 m (100 fathom) isobath. Dots indicate trawling locations for F/V *Huntress*. Locations trawled by F/V *Old Colony* overlap those of the *Huntress* in the vicinity of DeSoto Canyon (upper central part of map) and the area east of the Mississippi Delta.

second trip was 135 m. The average depth fished on trip 1 was 164 m, and the average depth on trip 3 was 179 m. Although catch rates >1000 kg/hour were recorded anytime between 0700 and 2000 hours, times of the largest catch rates were 0800-1630 hours. Very little was ever caught either before sunrise or after sunset.

The pattern of fishing by the *Old Colony* was less consistently variable than that of the *Huntress*. For instance, the difference in the average depth fished (150 m on trip 1 and 147 m on trip 2) was not statistically significant. This pattern, in turn, is reflected in the amount of product frozen per hour; although the average catch rate on trip 1 (1,309 kg/hour) was almost twice that of trip 2 (699 kg/hour) the difference was not significantly different from random. The depths trawled by the *Old Colony* during trips 1 and 2 ranged from 105 to 160 m. Four out of the five highest catch rates came from waters deeper than 150 m, and the two catch rates of >10,000 kg/hour were the two deepest tows made. As with the *Huntress*, average daily catch rates were highly variable. The pattern of catch rate related to time of day was quite similar to that of the *Huntress*.

Percentage of Butterfish in the Samples

Butterfish comprised 0-99 percent of the catch with great variability among tows. Except for the few tows made in comparatively shallow water (<85 m), neither temporal nor spatial variability in percentage of butterfish caught on the *Huntress* was significantly different from random. The shallow-water tows were all <5 percent butterfish. Subjectively, though, large total catches often were primarily butterfish whereas small total catches were mostly other species.

Size of Butterfish

Two size classes of butterfish were caught (Fig. 3), one of 7-11 cm SL and the other of 12-18 cm SL. Therefore, although the mean lengths of butterfish in the samples were calculated, the median length is a better overall representation of

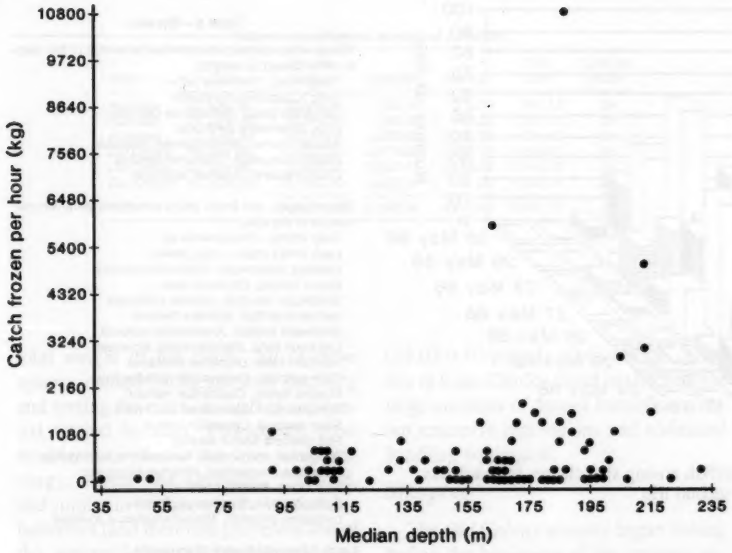

Figure 2.—Relationship between catch rate and bottom depth for the *Huntress*.

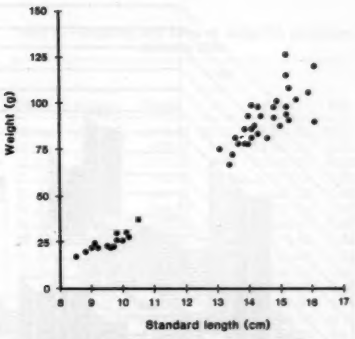

Figure 4.—Relationship of length to weight for sampled butterfish during May-June.

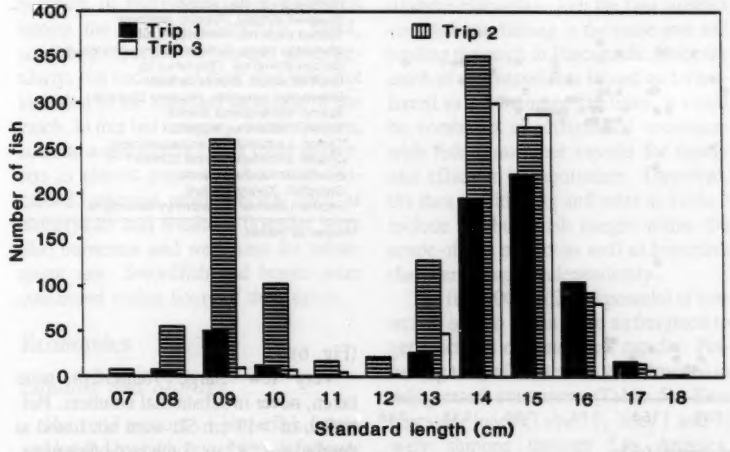

Figure 3.—Distribution of sampled butterfish among size classes for the three trips made by the *Huntress*.

butterfish size in the sample because lengths were not normally distributed. Based on a length-weight regression (Fig. 4), the larger group of fish was mostly within the commercially marketable weight range of >79 g, while the smaller fish were all well below marketable weight.

Substantially more of the 7-11 cm fish were caught on the *Huntress'* trip 2 than on either of her other trips (Fig. 3). Indeed, on some days during trip 2, these very small fish made up most of the catch (Fig. 5). Thus, the median size of butterfish on trip 2 was less than marketable size for 18 out of 52 tows, compared with 2 out of 30 tows on trip 1 and 1 out of 32 tows on trip 3. While this pattern could represent true temporal variability (e.g., relationship of catch with lunar cycle, etc.), an alternate explanation is that the fishing characteristics on trip 2 were different than on the other trips. Tows with small median length of butterfish were all from depths <170 m; As was stated above, the average depth of the tows on trip 2 (135 m) was within this depth zone and was significantly different than that on trips 1 (164 m) and 3 (179 m). A much larger data set would be needed to determine which of these explanations is correct.

No such relationship was evident between median size of butterfish and time of day. The two size classes were quite evident and each dominated some catches throughout the day. Differences among trips in the average time of day that tows were made were not statistically significant.

Butterfish are graded based on weight: "super-small", <80 g; "small", 80-100 g; "medium", 100-150 g; and "large", >150 g. The "super-small" butterfish are not generally marketable. The average weight of butterfish in the samples, which included both the large and the small length classes, followed patterns

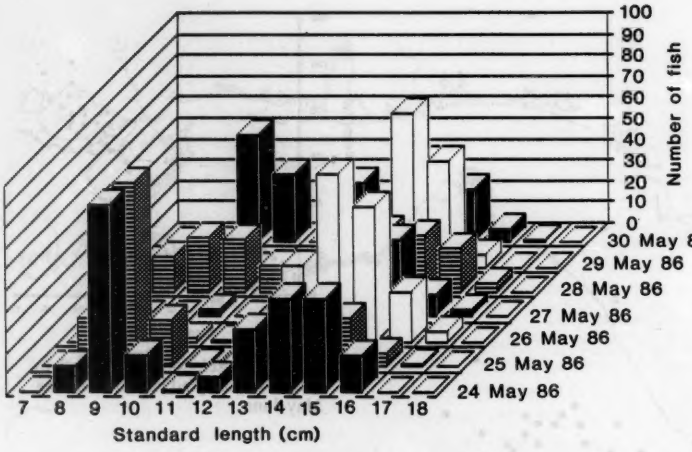

Figure 5.—Distribution of sampled butterfish among size classes for each day of *Huntress'* second trip.

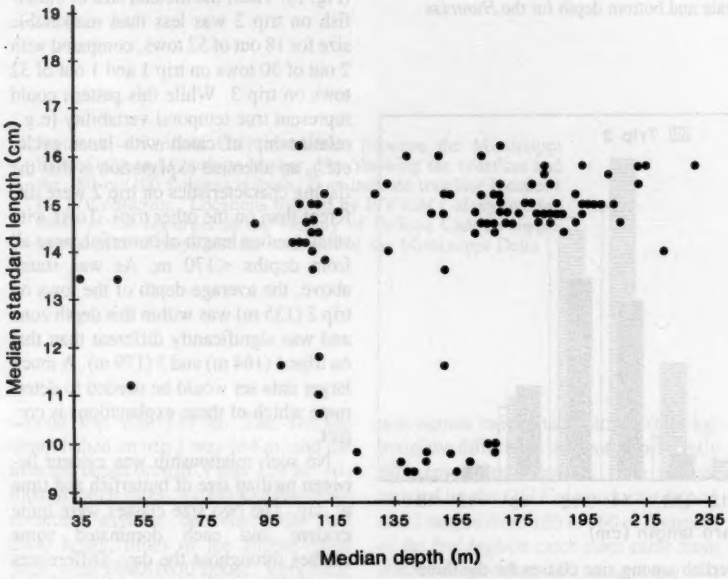

Figure 6.—Relationship of median length of sampled butterfish from *Huntress'* catches with bottom depth.

similar to those of median length. Average weight was marketable, either "small" or "medium", in 79 percent of the tows made by the *Huntress*. Most of the tows in which the average weight of butterfish was in the "super-small" range came from trip 2. Butterfish averaged "medium" in size in 36 percent of the samples and "medium" fish were particularly common in tows from deeper water (Fig. 6).

Very few "large" butterfish were taken, never in substantial numbers. Butterfish of >17 cm SL were not found at depths of <112 m. Such large fish were, however, taken on all trips and throughout the day.

Table 3.—Bycatch.

Fishes which sometimes comprised one-third of the catch or more (based on weight).
Rough scad, *Trachurus lathami*
Pinfish, *Lagodon rhomboides*
Longspine porgy, *Stenotomus caprinus*
Spot, *Leiostomus xanthurus*
Atlantic croaker, *Micropogonias undulatus*
Atlantic cutlassfish, *Trichiurus lepturus*
Chub mackerel, *Scomber japonicus*
Shrimp, squid, and fishes which sometimes were very numerous in the catch.
Rosy shrimp, *Parapenaeus* sp.
Long-finned squid, *Loligo pealei*
Freckled pike-conger, *Hoplunnis macrurus*
Round herring, *Etrumeus teres*
Smallscale lizardfish, *Saurida caribbaea*
Inshore lizardfish, *Synodus foetens*
Singlespot frogfish, *Antennarius radiosus*
Luminous hake, *Steindachneria argentaea*
Southern hake, *Urophysis floridanus*
Rock seabass, *Centropristis philadelphica*
Blueline tilefish, *Caulolatilus microps*
Wenchman, *Pristipomoides aquilonaris*
Silver seatrout, *Cynoscion nothus*
Red goatfish, *Mullus auratus*
Spinycheek scorpionfish, *Neomerinthe hemingwayi*
Longspine scorpionfish, *Pontinus longispinis*
Sea robins, *Prionotus* spp.
Dusky flounder, *Syacium papillosum*
Longspine snipefish, *Macrorhamphosus scolopax*
Large fishes which were often caught.
Silky shark, *Carcharhinus falciformis*
Blacktip shark, *Carcharhinus limbatus*[1]
Sandbar shark, *Carcharhinus plumbeus*
Dusky shark, *Carcharhinus obscurus*
Florida smoothhound, *Mustelus norrisi*
Scalloped hammerhead, *Sphyrna lewini*
Atlantic angel shark, *Squatina dumerili*
Roundel skate, *Raja texana*
Roughtail stingray, *Dasyatis centroura*
Spotted eagle ray, *Aetobatus narinari*
Blackedge moray, *Gymnothorax nigromarginatus*
Banded shrimp eel, *Ophichthus* sp.
Bearded brotula, *Brotula barbata*
Bluespotted cornetfish, *Fistularia tabacaria*
Scamp, *Mycteroperca phenax*
Bigeye, *Priacanthus arenatus*[1]
Tilefish, *Lopholatilus chamaeleonticeps*
Greater amberjack, *Seriola dumerili*[1]
Atlantic bonito, *Sarda sarda*
Swordfish, *Xiphias gladius*
Southern flounder, *Paralichthys lethostigma*[1]

[1]Frozen for market.

Bycatch

Substantial catches of nontarget species were occasionally a problem, especially when catches of butterfish were small. By-catch species (Table 3) can be divided into three categories. First, some species were both abundant and large enough to contribute substantially to the

Table 4.—Landing and storage of butterfish.

Vessel	Date	Pounds landed	Unloading	Storage	Total cost	Cost per pound
Huntress	22 May 86	22,904.00	465.14	376.38	841.52	.04
Huntress	02 June 86	32,646.00	746.00	489.32	1,235.32	.04
Huntress	10 June 86	104,196.00	2,908.50	1,365.72	4,274.22	.04
Old Colony	16 May 86	122,223.00	2,174.50	1,672.12	3,846.62	.03
Old Colony	28 May 86	75,850.00	2,340.41	1,069.92	3,410.33	.04
Old Colony	17 June 86	111,552.00	4,933.75	.00	4,933.75	.04
Total		469,371.00	13,568.30	4,973.46	18,541.76	.04

Table 5.—Shipping and sales of butterfish (container loads) in 1986.

Date	Pounds shipped	Freight	Cost per lb	Price	$/lb
19 May	37,723	2,475.00	$0.07	23,011.03	$0.61
20 May	39,435	670.00	0.02	23,661.00	0.60
20 May	39,435	2,475.00	0.06	23,661.00	0.60
05 June	37,504	750.00	0.02	22,877.44	0.61
10 June	35,812	900.00	0.03	21,487.20	0.60
16 June	37,584	686.75	0.02	23,677.92	0.63
16 June	37,687	1,100.00	0.03	23,742.81	0.63
16 June	37,521	1,100.00	0.03	24,013.44	0.64
16 June	36,487	1,100.00	0.03	24,081.42	0.66
17 June	36,487	683.75	0.02	24,081.42	0.66
17 June	37,184	686.75	0.02	21,566.72	0.58
17 June	41,111	1,178.75	0.03	29,188.81	0.71
18 June	37,632	1,200.00	0.03	26,718.72	0.71
23 June	36,113	1,541.00	0.04	15,528.59	0.43
24 June	39,056	1,300.00	0.03	25,776.96	0.66
25 June	37,806	1,614.00	0.04	26,086.14	0.69
Overall	604,577	19,484.00	$0.03	379,160.62	$0.63

total weight of the catch. All of these species caused problems with handling and sorting the catch, as well as substantial wasted biomass. Perhaps the most troublesome of all was the longspine porgy, which was abundant, common, and similar in thickness to the marketable butterfish (and therefore prevented use of the automatic sorting machines), and which had dorsal spines that made manual sorting painful and difficult. Second, some species were numerous, although some of these were quite small, and large numbers of individuals were destroyed during the trawling operations. Third, some large species were caught quite regularly, but because of their size were not included in the standard sampling of the catch. In this last category, some species, such as angel sharks, were quite numerous in almost every tow but were discarded, whereas other species, such as amberjacks and southern flounder were also numerous and were kept for subsequent sale. Swordfish and bonito were consumed within hours of their catch.

Economics

Landing and Storage

The total amount of butterfish frozen and landed by each vessel was as follows: *Huntress*, 71,886 kg (159,746 pounds); *Old Colony*, 139,331 kg (309,625 pounds). All cargo was unloaded and stored in Pascagoula, Miss., except for trip 3 of the *Old Colony*, which was unloaded at and immediately shipped from Lake Charles, La. Although the overall cost per pound (unloading+storage) was about the same ($0.04/pound) in both places (Table 4), unloading costs were substantially higher in Lake Charles ($0.04/pound) than in Pascagoula ($0.02-0.03/pound). Cold-storage facilities in Lake Charles could not be used for large amounts of frozen butterfish without extensive renovations and additional handling equipment.

Shipping

The *Old Colony* actually began fishing before the beginning of the contract period, and both vessels continued fishing beyond the end of the contract period. Furthermore, their marketing firm, Seafreeze Ltd., had another vessel, the *Atlantic Harvester*, join the two contract vessels butterfishing in the same area and landing the catch in Pascagoula. Once the catch of any vessel was landed and transferred to cold-storage facilities, it could be combined in refrigerated containers with fish from other vessels for timely and efficient transportation. Therefore, the data on shipping and sales in Table 5 include the butterfish caught within the scope of this project as well as butterfish that were caught independently.

The first 900 kg (2,000 pounds) of butterfish sent to Japan were airfreighted to get reactions of consumers rapidly. Following that, all butterfish were trucked in refrigerated containers (Table 5). Two container loads (Tables 5, lines 1 and 3) were shipped through Los Angeles, Calif., for minimum transit time. All other container loads were shipped through Savannah, Ga. The cost per pound of shipping through Los Angeles was substantially greater than that of shipping through Savannah.

Marketing

Before the beginning of this project, concerns had been raised about the marketability of gulf butterfish because of a high infestation rate by parasites (larval tapeworms found encysted along the backbones of many gulf butterfish). These preliminary concerns about parasites proved to be largely unfounded. Fat content at this time of year also appeared to be acceptable to consumers in Japan. After aggressive marketing by Seafreeze, the product sold well, averaging $0.63/pound. This was about 75 percent of the value of Atlantic butterfish caught and shipped from New England. Seafreeze sold all of its catch despite a sales contract that allowed the buyer almost unlimited flexibility to cancel. No negative comments about product quality were received.

Discussion

The life history of the gulf butterfish has been described by Murphy (1981), based primarily on samples from the Texas shelf. A bimodal size distribution similar to that presented above is also found off Texas. Murphy (1981) proposed that the two size classes represent recruitment from two annual spawning peaks (spring and fall), rather than two separate year classes. He therefore concluded that most butterfish off Texas spawn and die at the age of about 1 year. There are some indications, though, that butterfish in the north-central Gulf may have a life span of 2½ years (Gledhill[1]).

Murphy (1981) also demonstrated that gulf butterfish undergo an ontogenetic

(i.e., related to age and growth), cross-shelf migration. Spawning occurs in spring and fall on the outer continental shelf. Eggs and larvae are carried inshore by surface currents, and juveniles recruit to the bottom on the inner shelf. The butterfish then move into progressively deeper water as they grow and mature. This life-history pattern explains why fishing in water shallower than 150-170 m often results in catches composed mostly of the smaller of the two size classes. It also explains why the large catches of marketable butterfish all came from the outer shelf, in waters not trawled for traditionally exploited fishery resources in the Gulf of Mexico. Thus, commercial trawling for gulf butterfish probably should be confined to waters deeper than 150 m, at least during May and June.

Gulf butterfish were caught mostly during daylight hours, as is the catch pattern for the Atlantic butterfish (Murawski et al., 1978). This pattern probably results from diel vertical migration, in which the fish aggregate close to the bottom during the day and move upward at night to feed and perhaps to spawn. Thus, bottom trawling would be successful only during the daytime period of aggregation. Midwater trawling at night has been attempted on NMFS research cruises but has not proven to be very successful (A. Kemmerer, NMFS, Pascagoula, Miss., personal commun., 1986). It therefore appears that the U.S. East Coast strategy of bottom trawling during the day and laying to at night is appropriate in the Gulf of Mexico as well.

Small-scale patchiness in the abundance of gulf butterfish was very evident on the fishing grounds. Sequential tows within a very small area resulted in orders-of-magnitude changes in the amount of marketable butterfish caught and frozen. Furthermore, often three or more vessels would tow literally side-by-side and one of the vessels would catch tens of thousands of pounds while the others would catch merely hundreds of pounds. This is the pattern to be expected when very tight schooling occurs. An alternate explanation is that some physical condition is causing small-scale aggregation in this area. The outer continental shelf south of Mississippi is characterized by transient thermal fronts resulting from eddies off of the Gulf Loop Current (Fig. 7). A behavioral interaction of temperature preference with depth preference could cause small-scale aggregation unrelated to schooling behavior (R. Herron, NMFS, Pascagoula, Miss., personal commun., 1986). Regardless of the reasons for this patchiness, substantial variability in catch rate can be expected even within productive fishing grounds.

The contract requirements for this project were for two vessels, each to be committed for 30 days, including running time between port and the fishing ground and unloading time. In all, this work extended over about 1½ months (the beginning of May to the middle of June). It may be, however, that the project period, which ultimately was determined on legal and logistical bases, was neither optimum nor representative of conditions during a sustained fishery. Information on possible seasonal changes in the fishery is very limited. Seasonal changes are being investigated by the NMFS, though, and preliminary indications are that commercial butterfishing would be justified throughout the spring and in the late fall. Indeed, the optimum time appears to be in the spring; if so, the project period coincided with the end of the optimum annual period for butterfishing. The vessels working with Seafreeze continued fishing in the Gulf of Mexico through June and July. Catch rates declined as the warm season progressed, and during July they became so low that the vessels returned to New England.

The lack of statistically significant differences in catch characteristics among different types of trawling gear probably means that, given fairly large nets, net design has little to do with the ability to catch butterfish. If, however, fish in the dense small-scale aggregations inferred above do not all stay within 1-2 m of the bottom, a high-rise net, such as a semi-balloon shrimp trawl may be an advantage.

Ability to process the catch adequately is of utmost importance in maintaining the quality necessary to sell the catch in Japan, the primary market. It is possible to hold the fish for several days using methods like seawater/ice slurry, but the capability to freeze the catch onboard is an unquestionable advantage. Vessels outfitted with onboard freezers could be improved further by equipping them with refrigerated-seawater holding tanks to prevent extremely large catches from spoiling on deck before they can be processed completely.

Economic problems included high labor costs, lack of adequate onshore cold-storage facilities in southwestern Louisiana, and difficulties with land transportation to container ports. Upon arrival in Japan, though, sales of the product were better than expected. While this project was going on, the catch of Atlantic butterfish was very low. This probably stimulated consumer interest in the gulf butterfish and contributed to the success of the intensive efforts of Seafreeze to sell the gulf fish.

At $0.63/pound, the 211,217 kg (469,371 pounds) of gulf butterfish landed during this project would have a gross value of $295,704. After subtracting the costs of unloading, storage, and transportation, the value of the fish on the dock would be $263,081. Vessel costs must be estimated and may vary widely. In addition to operation costs such as fuel and provisions, repairs to nets, equipment (compressors, winches, chromascopes, etc.), and crew costs (figured on a share basis), such things as loan payments, insurance, and depreciation must be included in the estimate. If the Seafreeze bid price of $2,100/day/vessel is used as an estimate of actual cost (it included the cost of steaming from New England), then the net profit from this venture (not including special costs such as those involved in the intensive marketing effort in Japan) could be estimated to have been $137,081 or $2,285/vessel/day. It has been reported (Anonymous[3]) that in the Spring of 1987 "...two Seafreeze boats, the Persistence and the Atlantic Harvester, have arrived in the Gulf..." for another season of butterfish fishing.

[3]Anonymous. 1987. [News article.] Natl. Fisherman 67(13):22-23.

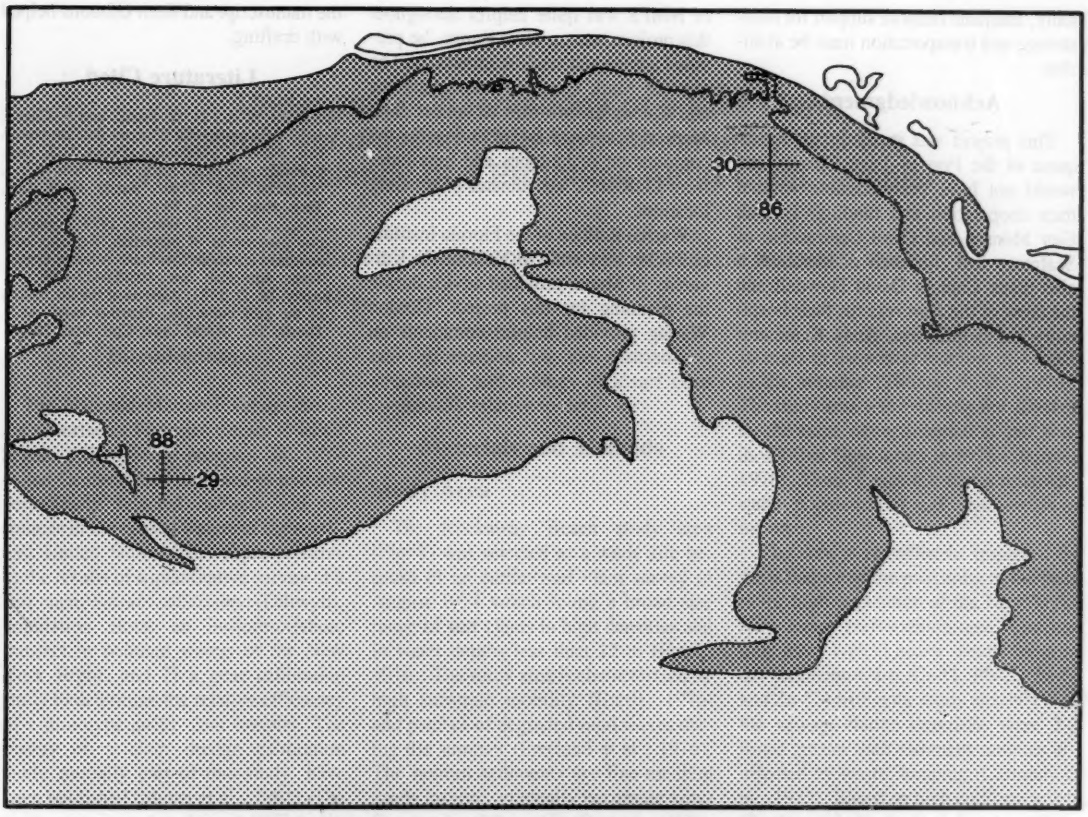

Figure 7.—Satellite image of the northern Gulf of Mexico taken on 22 May 1986. White areas are land. Dark shading of the water area indicates high concentrations of chlorophyll *a* from phytoplankton. The swirl in the central area is an eddy located in the vicinity of DeSoto Canyon and probably originating from the Loop Current. Such eddies are accompanied by rapid changes in water temperature.

Conclusions and Recommendations

1) It is possible to catch gulf butterfish in quantities and sizes which are commercially valuable, at least in late spring.

2) Commercial butterfishing in the Gulf of Mexico should concentrate on daytime bottom trawling on the outer continental shelf in waters deeper than 150 m.

3) Local vessels could be rigged with relative ease to catch gulf butterfish. Such conversions could be made so that local vessels could shrimp during part of the year and butterfish to supplement their income. Processing the catch, however, could be a substantial problem. Because of extended running times between deep water and ports with freezer facilities, techniques such as seawater/ice slurry are less viable as a processing option in areas with wide continental shelves than in areas with narrower shelves. Conversion to freezer trawling requires large vessels (about 100 feet or more), as does deep-water trawling a great distance from port. It therefore seems that only the largest local vessels should be considered for conversion to butterfish fishing.

4) Net profits potentially in excess of $2,000/vessel/day could make butterfish fishing an attractive option for local vessels. To expect such profits, though, certain conditions must be met. As in this project, whoever is marketing the catch must be experienced in dealing with potential customers, especially in Japan. The potential market, which currently is not large but which may be somewhat expandable, must not be saturated. Fi-

nally, adequate onshore support for cold-storage and transportation must be available.

Acknowledgments

This project was instituted at the request of the Port of Lake Charles and would not have been possible without their cooperation and funding. I thank Gier Monsen and Carol Centracchio of Seafreeze Ltd. for their cooperation. I also thank Captain David Dowdell and the crew of the *Huntress* for their hospitality and helpfulness. Andy Kemmerer of NMFS was quite helpful throughout this project; among other things, he provided advice and satellite images, and he allowed Mark Grace to accompany the *Old Colony* on two trips to collect data. Mark also assisted by arranging for the computation of latitudes and longitudes from LORAN-C coordinates of trawling locations.

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Underwater Observations of a Surf Clam, *Spisula solidissima* (Dillwyn), Community and the Relative Efficiency of a Prototype Airlift Clam Sampler

THOMAS L. MEYER, ERIC L. ANDERSON, JOHN W. ROPES, and WILLIAM C. PHOEL

ABSTRACT—A benthic infaunal community dominated by the surf clam, Spisula solidissima *(Dillwyn), was monitored near Rockaway Beach, Long Island, N.Y., during the summers of 1977 and 1978. In 1978, two distinct size groups were found with shell lengths ranging from 26 to 62 mm ($\bar{x}$ = 42.7 mm, age 2.5 years) and from 104 to 138 mm ($\bar{x}$ = 120.4 mm, age 11.5 years) and densities ranging from 480 to 924 ($\bar{x}$ = 730/m^2) and from 8 to 64 ($\bar{x}$ = 40/m^2) for the small and large modal groups, respectively. The larger clams burrowed to a depth of 12-14 cm with their siphons projecting up between the closely packed smaller clams which were burrowed 2-4 cm below the sediment-water interface. Individual clams burrowed to a depth approximately equal to their shell lengths. A slower growth rate was found in the study area compared with the average for the northeast U.S. coast. There may exist an inverse relationship between clam density and growth.*

An airlift system tested was designed to collect quantitatively a 0.25 m^2 sample. The airlift sampled between 0.25 m^2 and 0.50 m^2 of the bottom (70 percent overestimation) because of sediment slumping and scalloping around the perimeter of the dredge head. This resulted in more small clams being pulled into the sample from outside the quadrat area.

Introduction

The National Marine Fisheries Service's Northeast Fisheries Center (NEFC) began a long-term program in 1977 called Ocean Pulse, designed to monitor periodically selected habitats and resources in the coastal waters of the northeast United States. This paper presents 1) the results of a quantitative survey of a surf clam, *Spisula solidissima* (Dillwyn), population along an inshore-offshore transect in polluted waters of the New York Bight, and 2) a gear calibration study to determine the relative efficiency of a prototype airlift clam sampler. The results of a clam dredge calibration study, initially part of this study, have been published (Meyer et al., 1981). The study commenced in August 1977 to obtain information on the distribution, abundance, and ecology of a surf clam community relative to depth.

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Materials and Methods

Study Area

The Rockaway Beach study area (Fig. 1) was selected as a study site because of an earlier surf clam survey in August 1974 which found a broad size range of surf clams in high densities and in water depths less than 15 m (Franz, 1976). The study area is characterized by high substrate mobility (Harris, 1976) and patches of degraded sand waves during the summer (Freeland et al., 1976). The bottom sediments are fine-medium sands inshore, gradually becoming silty-fine sands offshore (Swift et al., 1976). Bottom currents are generally eastward along the Long Island shore (Charnell and Hansen, 1974), normal to our study transect. The mean tidal range is about 1.4 m (Swanson, 1976). A thermocline exists most of the year with bottom temperatures ranging from 5°C in the winter to 20°C in the summer (Thomas et al., 1976.) On the bottom, salinities range from 30 to 33‰ and dissolved oxygen 10 mg/l in the winter to a low of 1 mg/l in the summer (Thomas et al., 1976). The study area was evidently not affected by the large oxygen depletion and benthos kill of New Jersey in 1976 (Steimle, 1976). Thus, it was felt that a relatively stable population of surf clams exists in the area.

The area is nevertheless impacted by the influence of the proximity of the beds to the high population of the New York-New Jersey metropolitan area. Concentrations of typical heavy metals (ppm in dry sediment; Cu-6, Cr-11, Pb-28, Ni-6, and Zn-53) within the study area NNW of the sewage-sludge dumpsite were 2-3 times greater than sediment samples unaffected by waste dumping (Carmody et al., 1973). Based on high coliform levels (Buelow, 1968), the U.S. Food and Drug Administration (FDA) closed an area (Fig. 1) of about 380 km^2 to shellfishing in May 1970 (Verber, 1976). The closed area was circular, with a radius of 11 km, about the center (lat. 40°25'N, long. 73°45'W) of the New York sewage-sludge dumpsite (Gross, 1976). In April 1974 the FDA, in conjunction with the States of New York and New Jersey, closed a much larger area (Fig. 1) to

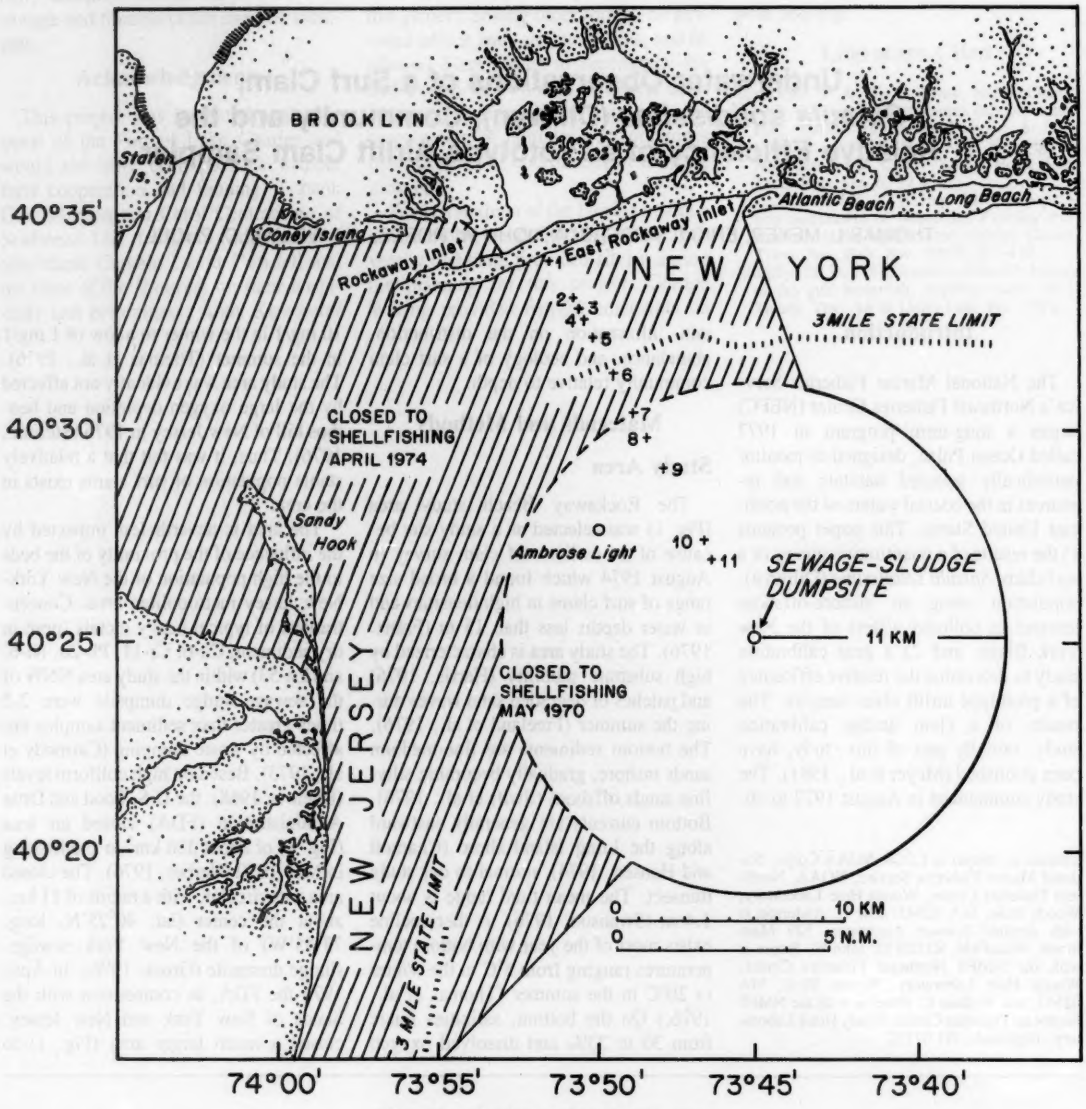

Figure 1.—Rockaway Beach study area.

shellfishing (Verber, 1976). As a consequence, the study area had a wide size range of surf clams within scuba diving depths, had been closed to commercial shellfishing (with the exception of a non-intensive bait fishery) since 1974, and had the potential of containing surf clams in significant numbers and in a relatively undisturbed state to facilitate our study of age and growth, mortality, and settlement.

Diver Transect Study

A NNW-SSE transect was established perpendicular to the Rockaway Beach, Long Island, N.Y. shore between lat. 40°33.9′N, long. 73°51.2′W, and lat. 40°26.8′N, long. 73°46.2′W (Fig 1). Eleven sampling sites on the transect were selected in regard to bathymetry beginning 0.9 km off the beach at a depth of 6.7 m and ending 15.5 km offshore at a depth of 29.6 m (Table 1). Station 11 was located 3.7 km from the center of the

Table 1.—Bottom characteristics.

Characteristic	Year	Station 1	2	3	4	5	6	7	8	9	10	11
Depth (m)	1977/78	6.7	9.8	10.7	12.2	13.4	15.5	18.3	21.3	22.9	27.7	29.6
Substrate	1977/78	Sand-gravel	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Silty fine sand	Silty fine sand	Silty fine sand	Silty fine sand	Silty fine sand
Depth of organic covering	1977/78	None	None	None	None	None	None	10 cm	10 cm	18 cm	18 cm	18 cm
Sand waves	1977	10-13 cm high 46 cm length	3-5 cm high 10-13 cm length	(<3 cm) high 6-8 cm length	None	None	None	(<3 cm) high 2-4 cm length	(<3 cm) high 2-4 cm length	None	None	None
	1978	None	None	3 cm high 8-10 cm length	3 cm high 6-8 cm length	None	None	None	None	None	None	None
Shell hash covering	1977	95% Surf clam	5% Surf clam	5% Surf clam	20% Surf clam	50% Surf clam	20% Surf clam	20% Surf clam	5% Surf clam	None	3% Ocean quahog	3% Ocean quahog
	1978	95% Surf clam	15% Surf clam	50% Surf clam	50% Surf clam	50% Surf clam	50% Surf clam	20% Surf clam	5% Surf clam	1% Ocean quahog	3% Ocean quahog	3% Ocean quahog
Bored clams	1977	Yes	None	None	None	Yes	None	None	None	None	None	None
	1978	None	Yes	None	None	None	None	None	None	None	None	None

sewage-sludge dumpsite. The differences in depths between adjacent stations ranged from 1.6 to 4.8 m. Stations 1-6 were within an area closed to commercial clamming by the FDA since April 1974, and Stations 7-11 since May 1970.

Scientists, equipped with scuba, worked in pairs during 1977 from the NOAA Research Vessel *Rorqual* and in 1978 from the NOAA Research Vessel *Kyma*, and collected 20 replicate samples at each transect station using a 0.25 m^2 quadrat grid (Fig. 2) hereafter referred to as a quadrat. Replicate sampling sites were chosen randomly at each station. The grid frame, constructed from aluminum angle stock 4 mm thick, was inserted into the sediment and made stationary throughout the sample collection. The divers worked barehanded. This maximized tactile contact and minimized the loss of clams and other animals in the turbid water above the disturbed sediment. The sediment was passed directly into nylon (mesh size (≤4 mm) collection bags and washed by shaking the bag leaving only coarse fractions of sediment and macrofauna. Care was taken to dig vertically in the grid frame to a sediment depth of about 25 cm. Divers made an approximate 6 m radius circular swim around the center of each station to describe conditions with respect to sediment type, topography, clam and benthic organisms, predators observed, and water visibility.

To determine clam distribution and patchiness in 1978 in the vicinity of Station 2, two quadrat samples were collected at each of 12 locations: 150 feet N, NW, W, SW, S, SE, E, and NE; and 300 feet N, W, S, and E of the center of Station 2. Distance and bearing were determined by marking off 150- and 300-foot lengths on a line and, while keeping the line taut, swimming the requisite bearing using an underwater compass.

In 1978, 53 clams were collected to determine growth rates. This was accomplished by measuring the internal growth lines exposed after thin-sectioning the chondrophore in the hinge (method described by Ropes and O'Brien, 1979). A sample (10 g net weight) of clam foot tissue from Stations 1, 2, 10, and 11 was analyzed on the Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer for heavy metals (method described by Wenzloff et al., 1979). Sediment samples were obtained at Stations 2 and 11 in 1978 using a Smith-McIntyre[1] bottom grab for bottom fauna analysis.

Airlift Bottom Sampler

An airlift system, under development at the University of Rhode Island, was tested as a quantitative clam sampler (Fig. 2). The system was specifically designed to operate in a surface-tended mode and to sample large bivalves, such as surf clams and ocean quahogs, *Arctica islandica*. During our tests, however, the sampler was diver-tended to appraise visually its sampling behavior.

The airlift system had a 0.25 m^2 steel head connected to a 3 m long airlift standpipe of 20 cm inside diameter (Fig. 2). A flexible PVC discharge hose of various lengths, depending on water depth, was attached to the standpipe and conducted samples into a removable nylon mesh collection bag (opening size ≤10 mm). Air was supplied to the standpipe through a 2 cm air hose from a low pressure air compressor rated at 40 cfm.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

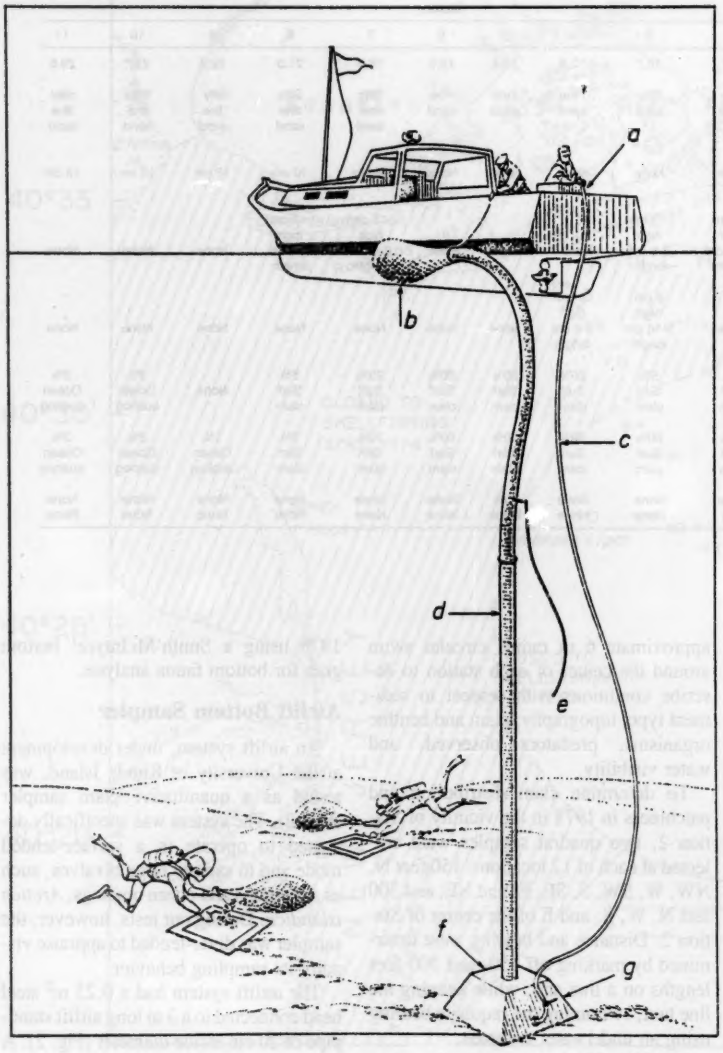

Figure 2.—Airlift system: a = air compressor, b = removable nylon mesh collection bag (opening size ≤10 mm), c = 2 cm air hose to the air compressor, d = 3 m long standpipe with an inside diameter of 20 cm, e = flexible PVC discharge hose in sections for desired water depth, f = 0.25 m^2 steel dredge head, and g = $\frac{1}{4}$ turn ball valve to regulate air flow. Diver system: h = scientist equipped with scuba gear, i = nylon mesh collection bag (opening size ≤4 mm), and 0.25 m^2 aluminum quadrant grid.

In operation, the dredge head and standpipe unit rested on the sediment with the standpipe in a vertical attitude. The collection bag was secured to the support boat at the surface. A diver controlled the volume of air entry through a quarter-turn ball valve on the dredge head. When the air was turn on, the flow into the dredge head caused water, sediment, and infauna to be flushed upward through the standpipe. Materials larger than 10 mm were retained in the collection bag at the surface. The dredge head penetrated to a sediment depth of about 25 cm. With slow bottom currents (<$\frac{1}{2}$ knot) and a stable moor by the surface platform, the discharge hose extended directly upward to the support boat. Recovery time for a sample was minimized in this configuration because the dredge head stayed on the bottom during replicated sampling. Surface to diver communication assured efficient use of the system in this mode.

In 1977 and 1978, the airlift was used to collect 20 replicate samples at Station 2 concurrently with 20 diver-collected samples for further calibration tests. A 90 cfm air compressor was substituted for in 1978 to enable the airlift to dig deeper and faster. In 1978, to determine if the airlift sampler was working efficiently, a sample of clams was marked and placed around the perimeter of the dredge head prior to sampling.

Treatment of Samples

The contents of each diver or airlift collection bag was sorted and the invertebrates removed for identification on board the support vessel. Samples containing large numbers of surf clams ≤65 mm shell length (hereafter defined as small clams) were subsampled to obtain at least 50 individuals for shell length measurements. Remaining small surf clams were counted. The shell lengths of all surf clams >65 mm (hereafter defined as large clams) were measured and the totals were added to the small clam totals for a grand total count per replicate sample. All ocean quahogs were measured for shell length, counted, and categorized with the same criteria used for surf clams. All measurements were to the nearest millimeter using a clam measuring board or calipers.

Results and Discussion

Diver Transect Study

Topography

The bottom topography along the transect was relatively featureless with a

Table 2.—Relative abundance of invertebrates and fish observed along transect. O-no sightings; P-present, ≤3 individuals; C-common, 4-14 individuals; and A-abundant, >14 individuals.

Species	Station and year																					
	1		2		3		4		5		6		7		8		9		10		11	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
Hydrozoan	O	O	O	O	O	O	O	O	P	P	O	P	P	P	O	P	O	O	O	P	O	P
Sea anemone, *Ceriantheopsis americanus* (Verrill)	O	O	O	O	O	O	O	O	O	P	P	C	P	P	A	P	A	C	C	C	A	C
Jellyfish, *Cyanea capillata* (L.)	O	O	O	O	O	O	O	O	O	O	O	O	O	P	O	O	O	O	O	O	O	O
Bryozoan	O	O	O	P	O	O	P	C	O	P	P	P	P	P	P	O	O	O	O	O	O	O
Moon snail, *Lunatia heros* (Say)	P	O	C	P	P	C	O	P	P	O	O	O	C	P	P	O	O	O	O	O	O	O
Ocean quahog, *Arctica islandica* (Linné)	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	P	O	P	P	C	C
Morrhua venus, *Pitar morrhuana* (Linsley)	O	O	C	C	C	C	O	O	P	O	O	O	O	O	O	O	O	O	P	P	P	P
Surf clam, *Spisula solidissima* (Dillwyn)	P	C	A	A	P	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Razor clam, *Ensis directus* (Conrad)	O	O	O	O	P	P	O	P	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Onuphis worm	O	O	O	O	P	P	O	P	P	P	O	P	O	O	O	O	O	O	O	O	O	O
Annelid (unidentified)	O	O	O	O	O	O	O	O	P	P	O	O	O	O	O	O	O	O	O	O	O	O
Horseshoe crab, *Limulus polyphemus* (L.)	O	O	P	O	P	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Mysid shrimp	O	O	O	O	O	O	O	O	O	O	O	O	C	P	A	P	C	P	C	P	O	O
Pandalid shrimp	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	P	C	P	O	P	A	P
Hermit crab, *Pagurus* sp.	O	O	O	O	O	P	P	P	O	P	O	P	O	O	C	P	O	C	C	P	O	P
Common rock crab, *Cancer irroratus* (Say)	O	O	P	P	P	O	O	O	C	P	O	O	O	P	O	P	P	C	O	P	C	P
Jonah crab, *Cancer borealis* (Stimpson)	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	C	P
Lady crab, *Ovalipes ocellatus* (Herbst)	P	O	C	C	O	O	O	O	O	O	O	O	P	O	C	P	O	O	O	O	O	O
Starfish, *Asterias forbesi* (Desor)	O	O	C	P	C	P	O	O	O	O	O	O	C	P	C	P	O	P	O	O	O	O
Skate, *Raja* sp.	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	P	O	O	O
Silver hake, *Merluccius bilinearis*	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	P	O	P	P	O	O
Spot, *Leiostomus xanthurus* Lacépède	O	O	C	O	C	O	O	O	O	O	O	O	O	O	P	O	O	O	O	O	O	O
American plaice, *Hippoglossoides plattessoides* (Fabricus)	O	O	O	O	O	O	O	O	O	O	O	O	O	O	P	O	O	O	O	O	O	O
Winter flounder, *Pseudopleuronectes americanus* (Walbaum)	O	O	O	O	O	O	O	O	O	O	O	O	O	O	P	O	O	O	O	O	P	O
Unidentified fish	O	O	O	O	O	O	O	O	O	O	P	O	O	O	O	O	O	O	O	O	O	O

gradual slope (<10°) from inshore to offshore. The substrate was sand-gravel at Station 1, fine sand at Stations 2-6, and silty fine sand at Stations 7-11 (Table 1). The five deepest stations (7-11), located within 11 km of the sewage-sludge dumpsite (Fig. 1), had a silty organic layer covering the fine sand. This organic layer completely covered the bottom to a depth of about 10 cm at Stations 7 and 8, and to a depth of 18 cm at Stations 9-11. In 1977, sand waves were observed at Stations 1, 2, and 3 with wave height/length profiles of 10-13 cm/46 cm, 3-5 cm/10-13 cm, and 3 cm/6-8 cm, respectively, and less than 3 cm/2-4 cm for Stations 7 and 8 (Table 1). In 1978, sand waves were found at Stations 3 and 4 with wave height/length profiles of 3 cm/8-10 cm and 3 cm/6-8 cm. Sand waves were previously described by Freeland et al. (1976) for this area and indicate a highly mobile substrate.

Surficial Overlay

Shell bits, fragments, and hinged and single valves of surf clams (shell hash) were found at Stations 1-8 with about 5-95 percent shell overlay as determined visually by divers (Table 1). The highest percentage (95 percent) was recorded at Station 1; the remaining seven stations varied from 5 to 50 percent each year. Station 3 showed the largest between-year variation (5-50 percent). Among these shell fragments, bored surf clams were noted at Stations 1 and 5 in 1977 and at Station 2 in 1978; each year, boring moon snails, *Lunatia heros*, were found at the same stations.

Hinged and single valves of ocean quahogs were found each year at Stations 10 and 11 and covered about 3 percent of the substrate. In 1978, an ocean quahog shell to substrate ratio of 1 percent was also found at Station 9.

Species Diversity

The surf clam was the most abundant megabenthic invertebrate collected during both years. Other invertebrates found in lower abundance were the sea anemone, *Ceriantheopsis americanus*; a mysid (unidentified); and a pandalid shrimp (Table 2). The most abundant fish observed was the spot, *Leiostomus xanthurus*. The invertebrates and fish associated with the surf clam population at Station 2 were: Bryozoans, moon snail, *Lunatia heros*; mud snail, *Nassarius trivittatus*; morrhua venus, *Pitar morrhuana*; Atlantic nut clam, *Nucula proxima*; horseshoe crab, *Limulus*

Table 3a.—Transect and airlift statistics: Clam size structure (mm).

Station	No. of diver/airlift samples collected		Total samples measured		Size structure (range in mm) and mean/standard error: Small surf clams (≤65 mm)		Large surf clams (>65 mm)		Ocean Quahogs	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
1	20	20	1	14	(42) 42/0	0	0	(66-142) 94.3/-	0	0
2	20	20	1,053/4,732	1,202/3,849	(20-51) 37.9/0.68	(26-62) 42.7/0.7	(104-142) 126.3/0.62	(104-138) 120.4/0.6	0	0
2[1]	20	10	1,060/7,896	532/3,274	(27-50) 38.7/0.63	(30-63) 43.5/0.7	(111-139) 125.3/0.61	(100-132) 120.9/0.7	0	0
3	20	20	1	0	(38) 38/0	0	0	0	0	0
4	20	20	0	0	0	0	0	0	0	0
5	20	20	0	0	0	0	0	0	0	0
6	20	20	0	0	0	0	0	0	0	0
7	20	20	0	0	0	0	0	0	0	0
8	20	20	0	0	0	0	0	0	0	0
9	20	20	1	0	0	0	0	0	0	(87) 87/0
10	20	20	2	3	0	0	0	0	(36-39) 38/-	(84-90) 87/-
11	20	20	9	5	0	0	0	0	(36-43) 38.8/-	(74-95) 83.7/-

[1]Airlift

Table 3b.—Transect and airlift statistics: Clam Density (m^2).

Station	No. of diver/airlift samples collected		Total samples measured		Density (range in m^2) and mean/standard error: Small surf clams (≤65 mm)		Large surf clams (>65 mm)		Ocean quahogs	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
1	20	20	1	14	<1	0	0	3	0	0
2	20	20	1,053/4,732	1,202/3,849	(524-1,368) 934/15.6	(480-924) 730/9.2	(0-48) 10/11.2	(8-64) 40/8.4	0	0
2[1]	20	10	1,060/7,896	532/3,274	(976-2,756) 1,588/22.4	(1,064-1,548) 1,296/9.2	(0-56) 7/11.2	(0-28) 13/5.2	0	0
3	20	20	1	0	<1	0	0	0	0	0
4	20	20	0	0	0	0	0	0	0	0
5	20	20	0	0	0	0	0	0	0	0
6	20	20	0	0	0	0	0	0	0	0
7	20	20	0	0	0	0	0	0	0	0
8	20	20	0	0	0	0	0	0	0	0
9	20	20	1	0	0	0	0	0	<1	0
10	20	20	2	3	0	0	0	0	<1	<1
11	20	20	9	5	0	0	0	0	<1	<1

[1]Airlift

polyphemus; rock crab, *Cancer irroratus*; lady crab, *Ovalipes ocellatus*; starfish, *Asterias forbesi*; and spot.

In 1977, the surf clam was highly concentrated at Station 2, virtually absent from Stations 1 and 3, and not present at Stations 4-11. Shell length measurements made on 22 percent (N=1,053) of the clams sampled by divers at Station 2 (Table 3a) comprised two distinct size groups (Fig. 3B). The small clams were consistently dense ($\bar{x}$ = 934 clams/m^2); the large clams occurred at low but variable densities (Table 3b). Large individuals were found in only 5 of the 20 quadrat areas samples. Surf clam (large and small) density was estimated at 944 clams/m^2. Ocean quahogs were found at Stations 9-11 in 1977 at densities < 1/m^2.

In 1978, the most abundant species in the quadrat samples was the surf clam and again they were highly concentrated at Station 2. Station 1 yielded 14 live specimens, in two distinct size groups; ten (10) of these clams measured between 66 and 83 mm ($\bar{x}$ = 76.1 mm; SE = 0.6) and four clams measured between 136 and 142 mm ($\bar{x}$ = 139.8 mm; SE = 0.2). At Station 2, shell length measurements made on 31 percent (N=1,202) of the clams sampled by divers (Table 3a) comprised two distinct size groups (Fig. 3D). The small clams were consistently dense ($\bar{x}$ = 730 clams/m^2); the larger clams occurred at significantly lower densities (Table 3b). Surf clam (large and small) density was estimated at 770 clams/m^2. Ocean quahogs were found at Stations 10 and 11 at densities ≤ 1/m^2.

Surf Clam Community

Distribution and Abundance

In 1978, surf clam distribution was determined by collecting 13 quadrat samples in a grid radiating 150 and 300 feet from the center of Station 2 (Fig. 4). Clam size was consistent throughout the sampling grid. In general, when the small clam density was above the grid mean,

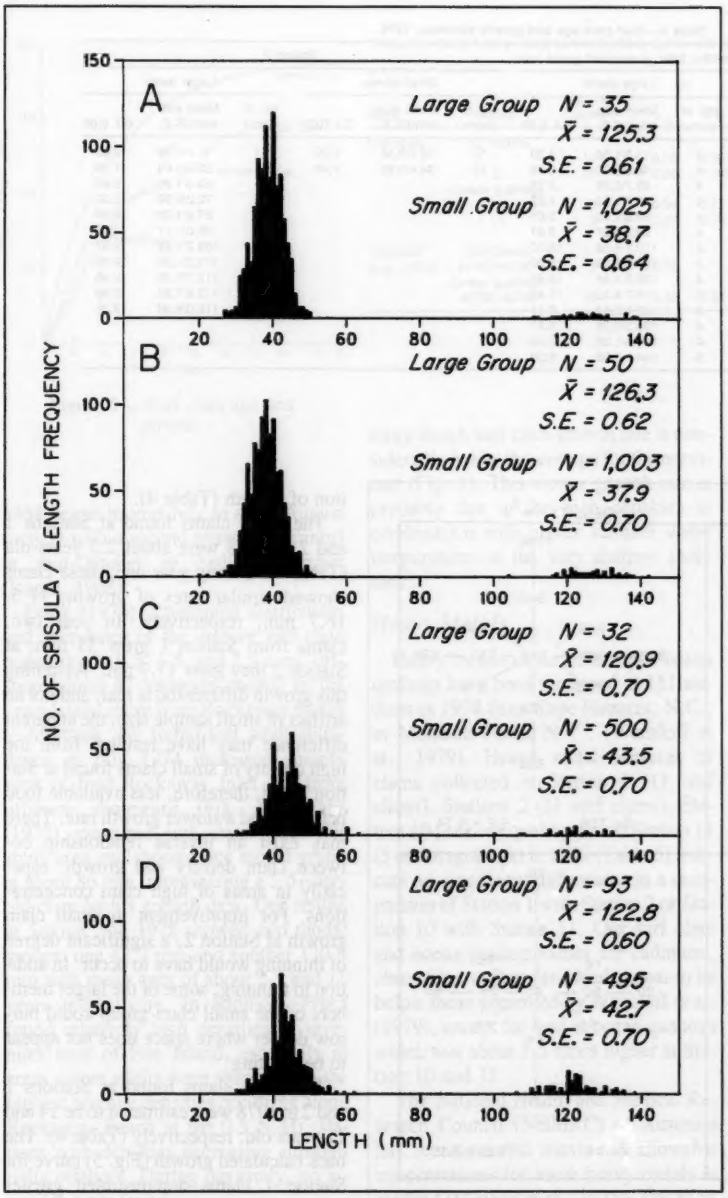

Figure 3.—Frequency distribution of shell lengths of *Spisula solidissima* in: A, 20 airlift collected samples in 1977; B, 20 diver collected samples in 1977; C, 10 airlift collected samples in 1978; and D, 10 diver collected samples in 1978.

the large clam density at the same location was below the grid mean and vice versa. This inverse relationship between large and small clam densities may be due in part to the amount of space available. The larger clams were found burrowed to a depth of 12-14 cm with their siphons projecting up between the closely packed smaller clams which were burrowed to 2-4 cm below the sediment water interface. In general, the surf clams at Station 2 burrowed to a depth about equal to their shell lengths. Divers saw the siphon opening of the larger clams much easier than the smaller ones. Some of the small clams appeared to be in small depressions. Density for the small clams was so high at Station 2 the clams were found physically touching their neighbors.

Meyer et al. (1981) estimated the surf clam density during two clam dredge efficiency tows near our study area. Two distinct size groups with means of about 31 and 112 mm were found. The small group comprised approximately 96.5 percent of the population. Densities ranged from 1,095 to 1,241 clams/m^2. During this study, densities were some 300 clams lower and means were about 10 mm higher. The proportion of small clams was virtually identical.

Age and Growth

In 1978, 12 surf clams (8 small, 4 large) from Station 1, and 41 (10 small, 31 large) from Station 2 were analyzed for age and growth (Table 4). Small clams in 1977 and 1978 at Station 2 increased in mean size from 37.9 to 42.7 mm; mean size of the large clams decreased from 126.3 to 120.4 mm (Table 3). This would suggest that the larger clams suffered some mortality. Since very few empty shells were found, the larger clams apparently either emigrated from this area or were moved by storm surges. The study area is characterized by an extremely high substrate mobility (Harris, 1976). This can be seen in the high percentage (up to 95 percent) overlay cover of surf clam shell hash found at Stations 1-7, and in sand waves which appeared at different stations each year; this also probably accounts for the occasional massive beaching of surf clams during winter storms (Jacot, 1919), and in the findings of Franz (1977) that living surf clams were always available on Rockaway Beach during his study. Apparently, the high substrate mobility and unknown environmental factors in this

Table 4.—Surf clam age and growth statistics, 1978.

	Station 1						Station 2					
	Small clams			Large clams			Small clams			Large clams		
Year of life	No. of clams	Mean size (mm)/S.E.	C.I. 0.05	No. of clams	Mean size (mm)/S.E.	C.I. 0.05	No. of clams	Mean size (mm)/S.E.	C.I. 0.05	No. of clams	Mean size (mm)/S.E.	C.I. 0.05
1	8	17.3/0.34	0.78	4	13.8/1.58	4.39	10	16.7/0.58	1.29	31	11.7/0.39	0.80
2	8	50.3/1.38	3.18	4	48.6/2.30	6.38	10	34.4/0.89	1.98	31	32.6/0.63	1.29
3				4	69.7/0.99	2.75				31	53.6/1.39	2.84
4				4	81.7/1.53	4.25				31	72.2/0.99	2.02
5				4	89.8/2.02	5.61				31	87.2/1.02	2.08
6				4	96.1/3.57	9.91				31	98.6/1.17	2.39
7				4	100.7/4.69	13.02				31	106.2/1.26	2.57
8				4	103.6/5.04	13.99				31	111.2/1.30	2.65
9				4	109.0/4.88	13.55				31	112.7/1.20	2.45
10				4	118.7/4.12	11.44				12	113.8/1.32	2.69
11				4	127.7/3.51	9.74				2	116.0/4.56	9.30
12				4	135.3/2.26	6.27						
13				4	140.3/1.28	3.55						
14				3	144.1/1.08	3.00						

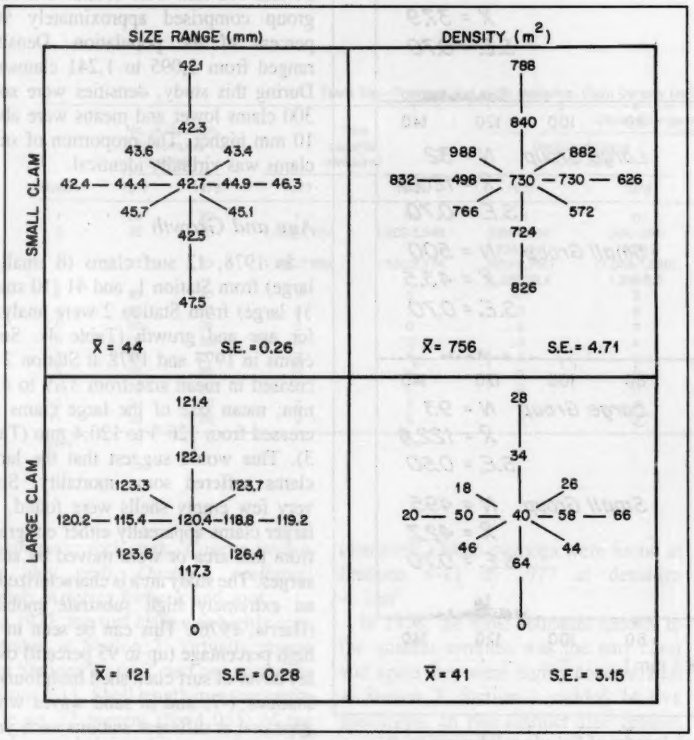

Figure 4.—Surf clam distribution and abundance 150 and 300 feet from center of Station 2.

area can partially or totally eliminate a clam bed during a 1-year period.

Age and growth were determined for clams from Station 2 by measuring internal growth lines. These clams were part of the group which showed the 4.8 mm increase. Measurements from the umbo to each annulus permitted back calculation of growth (Table 4).

The small clams found at Stations 1 and 2 in 1978 were about 2.5 years old (Table 4). During year one, these clams showed similar rates of growth, 17.3-16.7 mm, respectively. In year two, clams from Station 1 grew 33 mm; at Station 2 they grew 17.7 mm. Assuming this growth differential is real, and not an artifact of small sample size, the apparent difference may have resulted from the high density of small clams found at Station 2 and, therefore, less available food per clam and a slower growth rate. There may exist an inverse relationship between clam density and growth, especially in areas of high clam concentrations. For improvement in small clam growth at Station 2, a significant degree of thinning would have to occur. In addition to thinning, some of the larger members of the small clam group could burrow deeper where space does not appear to be limiting.

The large clams found at Stations 1 and 2 in 1978 were estimated to be 14 and 11 years old, respectively (Table 4). The back calculated growth (Fig. 5) curve for Station 1 clams demonstrated greater variability in rate than for Station 2, probably due to the small sample size.

Surf clams reach full sexual maturity during the second year with the smallest fully mature clam being about 45 mm long (Ropes, 1979b, 1980). The small clam population at Station 2 averaged 42.7 mm which is nearing sexual maturity. Spawning off New Jersey in 1962 to

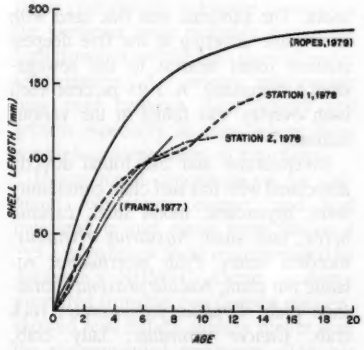

Figure 5.—Surf clam age and growth.

Table 5.—Mean heavy metal concentrations (ppm, wet weight) found in surf clams and ocean quahogs by station along transect in 1978 and results of Wenztloff et al. (1979).

Study	Station	No. of clams	Cd $\bar{X}$	Cd S.E.	Cu $\bar{X}$	Cu S.E.	Cr $\bar{X}$	Cr S.E.	Pb $\bar{X}$	Pb S.E.
Our study	Surf clams									
	1	11	0.03	0.007	0.73	0.16	0.48	0.19	0.39	0.19
	2	21	0.04	0.009	0.57	0.23	0.59	0.22	0.16	0.15
	Ocean quahogs									
	10	3	0.36	0.11	1.83	0.47	0.70	0.13	3.5	0.26
	11	5	0.27	0.05	1.56	0.64	0.72	0.28	2.9	0.67
Wenztloff et al. (1979)	Surf clams 41°00'-40°30'	3	< 0.12		3.83	0.78	< 0.62		< 0.7	
	Ocean quahogs 40°30'-40°00	15	0.42	0.34	5.33	0.40	< 1.23		1.0	

1964 began in mid-July to early August (major) with a second spawning (minor) in mid-October to early November (Ropes, 1968).

Franz (1976) determined distribution and abundance of the inshore surf clam population at 0.5, 1.5, and 2.5 n.mi. offshore along 47 transects normal to the Long Island shore from Rockaway Beach to Montauk. He found that adult abundance in July 1974 increased sharply west of East Rockaway Inlet and from offshore shoreward (Fig. 1). Franz (1976) measured surf clams near our study area and showed one modal group at about 86 mm, representing a 5.5-year-old clam by his growth data. Our results at Station 2 in 1978 showed two modal groups; one 42.7 mm and another 120.4 mm with mean ages of about 2.5 and 11 years respectively. In addition, Franz found relatively high densities of juveniles west of Fire Island, especially in areas where adults were sparse, with the highest juvenile densities occurring along Rockaway Beach at the 0.5 N.Mi. stations with densities decreasing substantially offshore. During our study, no juveniles were found.

Franz (1977) estimated surf clam growth from live specimens washed up along Rockaway Beach in May 1976 (Fig. 5). Both Franz's and our large clam age and growth curves (Fig. 5) when compared against Ropes (1979a), who calculated the general age and growth of surf clams along the northeast coast of the United States, indicate that the Rockaway Beach surf clam growth rate is considerably below the average for the northeast (Fig. 5). This slower growth rate is probably due to the high densities in combination with higher summer water temperatures at the very shallow study area.

Heavy Metals

Heavy metals in surf clams and ocean quahogs have been measured at 151 stations in 1974 from Cape Hatteras, N.C., to Montauk Point, N.Y., (Wenzloff et al., 1979). Heavy metal analyses of clams collected at Station 1 (11 surf clams), Stations 2 (21 surf clams), Station 10 (3 ocean quahogs), and Station 11 (5 ocean quahogs) in 1978 (Table 5) indicate no significant differences in a comparison of Station 1 with Station 2 or Station 10 with Station 11. Our surf clam and ocean quahog values for cadmium, chromium, copper, and lead appear to be below those presented by Wenzloff et al. (1979), except for lead in ocean quahogs which was about 2.5 times higher at Station 10 and 11.

The National Health and Medical Research Council (NHMRC) of Australia has recommended maximum allowable concentrations for some heavy metals in seafood (Mackay et al., 1975). The FDA is currently developing acceptable levels for heavy metal concentration in U.S. fishery products. The maximum concentrations (in ppm, wet weight) presented by NHRMC were: Cadmium 2.0, copper 30.0, and lead 2.0; chromium was not listed. Our values are below the NHMRC recommended maximums, except for lead in ocean quahogs at Stations 10 and 11. These values may have been high because of the proximity of these stations to the center of the sewage-sludge dumpsite (Fig. 1).

Table 6.—Analysis of bottom grab samples.

Species	Station 2 No. of individuals	Station 11 No. of individuals
Aschelminthes		
Nematoda		
Unidentified spp.		3
Mollusca		
Gastropoda		
Mud snail, *Nassarius trivittatus* (Say)	2	
Bivalvia		
Atlantic nut clam, *Nucula proxima* (Say)	2	46
Ocean quahog, *Arctica islandica* (Linne)		1
Verrill's diplodon, *Diplodonta verrilli* (Dall)		2
Northern dwarf cockle, *Cerastoderma pinnulatum* (Conrad)		2
Surf clam, *Spisula solidissima* (Dillwyn)	5	1
Northern dwarf tellin, *Tellina agilis* (Stimpson)		1
Annelida		
Polychaeta		
Pherusa affinis (Leidy)		4
Arthropoda		
Crustacea		
Amphopod, *Leptocheirus pinguis* (Stimpson)		1
Common rock crab, *Cancer irroratus* (Say)	*	2

Infauna

Analyses of the infauna in bottom samples collected at Station 2 and 11 in 1978 indicate a higher species diversity at the deeper station; from 4 to 10, respectively (Table 6). The most abundant species was the Atlantic nut clam with 46 indi-

viduals. Other invertebrates averaged from 1 to 5 individuals.

Airlift Sampler

In 1977, shell length measurements made on 13 percent (N = 1,060) of the clams sampled by the airlift at Station 2 (Table 2) comprised two distinct size groups (Fig. 3A). Small clams were consistently dense ($\bar{x}$ = 1,588 clams/m^2), larger clams occurred at low but variable densities. Large individuals were found in only 6 of the 20 quadrat samples collected. Surf clam (large and small) density was estimated at 1,595 clams/m^2. The airlift overestimated the density of small clams by 70 percent and underestimated the large clams by 43 percent; the overall population was overestimated by 69 percent. A significant difference was found in the mean number of clams sampled by the airlift and diver methods; no significant difference was found in the mean lengths.

In 1978, shell length measurements made on 16 percent (N=532) of the clams collected by the airlift in 10 quadrat samples at Station 2 (Table 2) comprised two distinct size groups (Fig. 3C). The small clams were consistently found in extremely high densities ($\bar{x}$ = 1,296 clams/m^2); the larger clams occurred at low but variable densities. Large individuals were found in 9 of 10 quadrat samples collected. Surf clam (large and small) density was estimated at 1,309 clams/m^2. After collecting 10 airlift samples in 1978, the results were compared with the first 10 diver collected samples (Fig. 3C, 3D). The airlift overestimated the density of small clams by 78 percent and underestimated the large clams by 68 percent; the overall population was overestimated by 70 percent. Shell length measurements were similar (0.8 mm difference). To confirm that the airlift was oversampling, 115 small clams and 5 large clams were marked and placed around the immediate outside perimeter of the dredge head as it rested on the bottom. The airlift then collected a sample; 79 of the small marked clams (69 percent) and 1 large clam (20 percent) were captured. Overall, 67 percent of all marked clams outside of the airlift head were captured. Because of the marked clam result and the apparent 70 percent overestimation of the first 10 airlift samples, the remaining 10 airlift samples were not collected. This large overestimation of the clam density, the closeness in shell length measurements, and the similarity in results between 1977 and 1978, made statistical tests unnecessary.

The overestimation of the surf clam population by the airlift sampler was also observed by divers over the 2-year study. The airlift collected between 0.25 m^2 and 0.50 m^2 of the bottom by overestimating small clam density (those oriented close to surface) and underestimating large clam density (those deeply burrowed). An airlift sample hole showed it to be mounded in the middle and the sediment became slumped and scalloped around the periphery upon removal of the dredge head. All larger clams near the inside periphery of the dredge head had been collected, but some of the larger clams remained in the middle. All of the smaller clams were collected. As the density of larger clams increased, so did the magnitude of underestimation. Nevertheless, both collecting methods sampled the clam population by shell length without bias.

The prototype airlift sampler, in its present configuration, is a complex system requiring at least a 15 m long surface support platform, three people on deck, and a tending diver to sample benthic macrofauna. It samples to a sediment depth of about 25 cm, collects replicate samples at a rate of 1.0-1.5 minutes per sample, and qualitatively collects macroinvertebrates down to a size of ≤ of 7 mm with less than 1 percent breakage.

The airlift sampling system tested shows promise as a surface-operated bivalve sampling tool. It has been successfully tested in a surface tended mode to a depth of 25 m. Through further modifications, specifically with regard to the overestimation of clam density, the airlift sampler should be capable of quantitative sampling. Once this capability is attained, the support required should be no more complex than other surface sampling systems.

Summary

The bottom topography in the study area was relatively featureless with a gradual slope (<10°) from inshore to offshore. The substrate was fine sand with an organic covering at the five deepest stations (ones nearest to the sewage-sludge dumpsite). A 1-95 percent shell hash overlay was found at the various stations.

Invertebrates and fish found directly associated with this surf clam community were: bryozoans, moon snail, *Lunatia heros*; mud snail, *Nassarius trivittatus*; morrhua venus, *Pitar morrhuana*; Atlantic nut clam, *Nucula proxima*; horseshoe crab, *Limulus polyphemus*; rock crab, *Cancer irroratus*; lady crab, *Ovalipes ocellatus*; starfish, *Asterias forbesi*; and spot, *Leiostomus xanthurus*.

The surf clam community measured in 1978 showed two distinct size groups. Shell lengths ranged from 26 to 62 mm $\bar{x}$ = 42.7 mm, age 2.5 years) and from 104 to 138 mm ($\bar{x}$ = 120.4 mm, age 11.5 years); densities were 730 clams/m^2 and 40 clams/m^2, respectively. No juveniles were found. There appears to exist an inverse relationship between the densities of large (>65 mm) and small (≤65 mm) clams. In general, as the density of one group increases, the density of the other decreases and vice versa. This is probably due in part to the amount of space available.

Large clams burrowed to a depth of 12-14 cm with their siphons projecting up between the closely packed smaller clams which were burrowed to 2-4 cm below the sediment water interface. Surf clams burrowed to depths about equal to their shell length. Smaller clams were found to be physically touching their neighbors.

Analyses of in between-year growth increments and back-calculated growth suggests that larger clams suffered some form of mortality. Since very few empty shells were found, the larger clams apparently either emigrated from this area or were moved by storm surges. In 1978, comparison of growth statistics for small clams at Station 1 and 2 indicated similar growth rates for year one, 17.3-16.7 mm. In year two, clams at Station 1 showed a faster rate of growth of 33-17.7 mm. The slower growth rate of the small clams found at Station 2 may have resulted from high densities and less available food per clam.

Rockaway Beach surf clam growth

rate is considerably below the average for the northeast coast probably due to the high densities and the high summer water temperatures. An inverse relationship may exist between clam density and growth especially in areas where there are high concentrations of the clams.

Heavy metal concentrations for cadmium, chromium, copper, and lead measured in surf clams from Station 1 and 2 were below those recommended by Australia's NHMRC. Ocean quahogs, measured from the two deepest stations, showed lead values slightly higher than the recommended maximum allowable concentration for that metal in seafood by NHMRC. The value for lead may have been higher because of the closeness of the stations to the center of the sewage-sludge dumpsite.

Infauna samples collected from Station 2 and 11 in 1978 indicated a higher species variability at Station 11 (the deepest station), 4 and 10, respectively. The most abundant species was the Atlantic nut clam, *Nucula proxima*, with 46 individuals found at Station 11. Other invertebrates averaged from 1 to 5 individuals.

The airlift system tested shows promise as a surface-operated bivalve sampling tool. It was designed to quantitatively collect 0.25 m^2 samples, but it overestimated the small clam density by 78 percent and underestimated the large clam density by 68 percent, with an overall overestimation of 70 percent. The airlift sampled between 0.25 m^2 and 0.50 m^2 of the bottom by pulling in small clams into the sample from outside the quadrat area. The resultant hole was mounded in the middle and the sediment became slumped and scalloped around the periphery upon removal of the dredge head. All of the larger clams near the inside periphery of the dredge head had been collected, while some of the larger clams remained in the middle. All of the smaller clams were collected. Through further modifications, specifically with regard to the overestimation of clam density, the airlift sampler should be capable of quantitative sampling. Once this capability is attained, the support required should be no more complex than other surface sampling systems.

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Manufacturing of a Crab Analogue to Determine the Quality of U.S. Shore-based Produced Surimi

JERRY K. BABBITT and KERMIT D. REPPOND

Introduction

In 1986, Alaska Pacific Seafoods Inc.[1] (APS) in Kodiak, Alaska, produced over 1.8 million pounds of surimi, successfully completing the first commercial U.S. production of surimi funded by a National Marine Fisheries Service Saltonstall-Kennedy grant through the Alaska Fisheries Development Foundation. This has provided the impetus for U.S. companies to begin production of surimi and fabrication of seafood analogues from Alaska pollock, *Theragra chalcogramma*.

At present, laboratory tests can define certain properties of surimi, but further work is needed to relate the results of these tests to the ability of the surimi to form a seafood analogue (Reppond et al., 1987b). The purpose of this study was to monitor closely the production of surimi and to relate the chemical and functional properties of the surimi to its performance in the fabrication of a crab analogue.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

ABSTRACT—The chemical changes in Alaska pollock, Theragra chalcogramma, *flesh were monitored during the shore-based production of surimi. The ability of the surimi to produce a crab analogue was then related to the chemical and functional properties of the surimi. The results indicated that the frozen storage stability and chemical composition of surimi produced using an in-line washing system were equivalent to surimi produced using a conventional batch-type process. The results also demonstrated that shore-processed surimi can be used to produce an excellent crab analogue.*

Materials and Methods

Raw Materials

Alaska pollock were caught between the afternoon of 12 November 1986 and the evening of the 13th by the F/V *Arcturus* and held using a flooded refrigerated seawater (RSW) system (Gwinn, 1987). The pollock were off-loaded by a pneumatic fish pump the evening of the 13th and production of surimi started at 1:00 a.m. on the 14th. The surimi process was similar to that used in Japan (Lee, 1984) except Baader 182 and 184 filleting machines and an in-line washing system described by Kelly (1986) were used to prepare and wash the minced pollock flesh.

Samples of fillets, minced, and washed minced pollock flesh for chemical analyses were taken at 1:00 p.m. on the 14th. The fillet sample was taken from the end of the Baader skinning machine, the minced sample from the Baader 695 meat separator, and the washed minced sample from the end of the rotary dewatering screens. After an elapsed time of 30 minutes to allow for the washed minced pollock flesh to pass through the screw-press dehydrator, five batches (137 kg each) of surimi (containing 4 percent sugar, 4 percent sorbitol and 0.3 percent tripolyphosphate equivalent to the weight of pollock flesh) were prepared for testing. The 72 blocks (10 kg each) of surimi were plate-frozen, shipped frozen by Sea-Land, and held at UniSea, Inc., Redmond, Wash., until evaluated.

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Chemical Analyses

The analyses for moisture, protein (total N × 6.25), fat, ash, and salt were determined according to AOAC procedures (AOAC, 1980). Minced fish samples were extracted with trichloroacetic acid according to the method of Bullard and Collins (1980). Trimethylamine oxide was determined by the method of Dyer et al. (1952), except, trimethylamine was measured using the method recommended by Bullard and Collins (1980).

Surimi Quality

Frozen surimi quality standards (Suzuki, 1981; Lee, 1984) were used to evaluate the surimi, and the properties of the frozen surimi were determined according to the method of Reppond et al. (1987b).

Crab Analogue Fabrication

The evaluation of the surimi was conducted on 9 December 1986 by UniSea, Inc. in Redmond, Wash. Routine procedures for formulating and processing the crab analogue were followed.

Results and Discussion

Raw Materials

Pollock used in this study averaged

Table 1.—Temperatures of pollock flesh during surimi processing.

Category	°C	°F
Minced flesh	0-2	32-36
After rotary screens (washing)	6	43
After refining	7	45
After screw-press (dewatering)	8	46
After mixing (surimi)	10	50

Table 2.—Effect of washing on the composition of minced pollock flesh.

Item	Pollock - 11/14/86 In-line system			02/06/85[1] Batch system	
	Fillet	Mince	Washed mince	Mince	Washed mince
Percent					
Moisture	82.01	82.14	91.58	82.88	92.78
Protein (N × 6.25)	15.80	15.90	8.10	16.20	7.30
Lipid	0.50	0.49	0.28	0.60	0.30
Ash	1.16	1.10	0.17	1.06	0.13
Percent (dry wt.)					
Protein	90.49	90.91	94.74	90.70	94.43
Lipid	2.87	2.80	3.27	3.36	3.88
Ash	6.64	6.29	1.99	5.94	1.69
TMAO (mgN/100g)	76.0	71.3	8.7	65.1	4.2
TMA (mgN/100g)	0.40	0.56	0.10		
NaCl (%)	0.24	0.24			
pH	7.08	7.10	7.21		

[1]Babbitt et al. (1986).

Table 3.—Functional properties of surimi.

Item and time	Setting at 90°C for 40 min.	Setting at 40°C for 20 min., then 90°C for 20 min.
Frozen storage (−18°C)		
One Week		
Force (g)	548 ± 34	702
Depression (mm)	14.5 ± 0.5	16.2
Gel strength (g/cm)	795 ± 53	1,144
Moisture (%)	75.2	
Three Months		
Force (g)	571 ± 62	733
Depression (mm)	14.0 ± 0.9	15.5
Gel strength (g/cm)	805 ± 130	1,136
Moisture (%)	75.4	
Six Months		
Force (g)	514 ± 61	
Depression (mm)	13.7 ± 0.6	
Gel strength (g/cm)	706 ± 107	
Moisture (%)	75.6	

48.2 cm (19 inches) in length and 1,362 g (3.0 pounds) in weight (range 1.5-5.0 pounds). The pollock were in good condition and the delay of time from catching to processing was 25-49 hours. The temperatures of the pollock flesh at various stages during processing are shown in Table 1. Comments have been made on temperature controls for trawler production of surimi (Hilderbrand, 1986), but no specific temperatures during production have been reported.

Chemical Analyses

The results of the chemical analyses are shown in Table 2. Under laboratory conditions, Reppond et al. (1987a) reported the salt content of fillets from pollock held in RSW (2 parts fish to 1 part seawater maintained at from 0 to −0.5°C) for 2 days was 0.27 percent which is in good agreement to that found in pollock held under the conditions in this study. The high trimethylamine oxide (TMAO) content of 76 mgN/100g indicated the pollock were very fresh. However, the trimethylamine (TMA) content of the fillets (0.40 mgN/100g) was slightly higher than similarly held pollock (0.23 mgN/100g) reported by Reppond et al. (1987a).

The results of a study by Babbitt et al. (1986) have been included in Table 2 to compare the "completeness" of the washing method used in this study with the traditional batch system using 3 washings of 1 part fish with 2 parts water. The results indicated the in-line washing produced a washed mince equivalent to that of the 3-cycle batch system. Nearly all the nitrogenous compounds (represented by TMAO) were removed in both systems and on a dry weight basis the protein content of the washed minced flesh was over 94 percent.

Surimi Quality

Presetting the samples for 20 minutes at 40°C increased gel strength values (Table 3). The high depression values of 16.2 and 15.5 mm indicated that the surimi possessed excellent flexibility and was comparable to surimi produced at sea by a factory ship (Reppond et al. 1987b). Also, the significant increase in the gel strength values by presetting the gels at 40°C for 20 minutes may be an indication that the pollock were very fresh.

The force, depression, and gel strength values for the 40-minute setting at 90°C indicated no significant changes ($P < 0.05$) occurred in the functional properties of the surimi during 6 months of frozen storage at −18°C. Thus, the stability of the surimi during frozen storage indicated that the surimi produced from the in-line washing system was similar to surimi produced using a conventional batch-type process.

The surimi performed very well during the production run of chunk-style crab, as the formula used by UniSea to fabricate the crab analogue resulted in an excellent product. The results from informal sensory evaluations indicated that the color, texture and desirability of the chunk-style crab was very good and comparable to other commercial products.

Conclusions

The results indicated that the chemical composition of the in-line washed surimi produced at APS was equivalent to surimi produced using a conventional batch-type process. Also, pollock held in RSW can be used to produce a high quality surimi. Most importantly, the results demonstrated that shore-based produced surimi can be used to produce an excellent crab analogue. Various parameters were measured during the production of surimi and this information can serve as a basis for predicting the functional properties and frozen shelf-life stability of surimi.

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Ozone Treatments of Fresh Atlantic Cod, *Gadus morhua*

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ABSTRACT—The effect of ozone was investigated by various applications on the iced storage life of fresh gutted Atlantic cod, Gadus morhua. *The different treatments incorporated the ozone in either the ice, rinse water, or chilled seawater. Shelf life, as assessed by sensory, chemical, and microbiological tests, was not sufficiently extended by any of the treatments.*

Introduction

The strong oxidizing nature of ozone, known since its discovery in 1840, has made it a useful agent for seawater disinfection (Blogoslawski et al., 1975; Blogoslawski, 1977) by effectively destroying bacteria, yeasts, and viruses. Its potential value for shellfish depuration was first reported by Voille (1929) and later by Salmon and Le Gall (1936). More recently, Blogoslawski and Stewart (1977) cited in a review article numerous reports of the successful use of ozone to 1) control microbial populations in closed marine systems, 2) depurate shellfish, 3) improve water quality and prevent disease in aquaculture, 4) inactivate red tide toxins, and 5) prevent biofouling, i.e. the rapid and undesirable growth of aquatic flora and fauna which can plug mechanical systems.

Ozone has been reported in numerous studies to extend the storage life of many perishable foods by slowing decomposition caused by microorganisms. These studies were reviewed by Farquhar and Rice (1982). Storage life extension of fish using ozone was first reported by the French investigators Salmon and Le Gall (1936). They found they could extend the storage life of whiting 4 days by rinsing the fish with freshly ozonated seawater and then packing them in small boxes with ozonated ice.

Interest in the use of ozone for fish quality preservation was not then sustained, but resumed about 30 years later when Japanese investigators (Haraguchi et al., 1969) reported a 4-day storage life extension by ozonation of brine-dipped jack mackerel and striped mackerel.

In a more recent study (Nelson, 1982), tests were conducted to determine whether the storage life of freshly caught Alaska salmon, *Oncorhynchus* spp., could be extended by packing the fish in ice made from ozonated water compared with fish conventionally packed in ice made from nonozonated water. The bacterial count on the fish kept in ozonated ice (94×10^3/g) was only 3 percent of that on fish packed in regular ice (2.7×10^6/g) after 8-9 days storage at 28°F. The results of this study indicated that the fresh quality of ozone-iced Pacific salmon can be maintained up to 6 days. And, DeWitt et al. (1984) report a "possible" extension of 1-2 days in the storage life of Gulf of Mexico shrimp with the use of ozonated ice.

The nature and rate of deterioration varies considerably with different species (Bramsnaes, 1965); therefore, the purpose of our study was to determine if the use of ozone could, by various treatments, extend the storage life of gutted cod as it appears to do with some other species of fish.

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Materials and Methods

This study was conducted in two parts. For Part I, 36 eviscerated cod (3.5-6 pounds each) 1-day post mortem, were procured from a Gloucester, Mass., day boat in March, 1984. These fish were held in ice for 24 hours while fresh ozonated ice was prepared. They were then sprayed with tap water and divided into three treatment groups of 12 fish each. The treatments were: 1) Control samples stored in freshwater flake ice, 2) rinsed for one minute with 500 ml of freshly prepared ozonated water, while suspended by their tails, then stored in flake ice, 3) stored in 2 inch cube-sized chunks of ozonated ice.

The fish were stored in commercial plastic fish boxes (125-pound capacity). Each box contained six fish divided into two layers of three fish and was covered with a sheet of polyethylene during storage. The boxes were kept at an ambient temperature of about 37°F. Two fish from each group were tested after 0, 5, 9, 13, 16, and 20 days of treatment (2, 7, 11, 15, 18, and 22 days post mortem). One fillet from each fish was used for bacteriological analyses and sensory evaluation, and the second was used for pH and chemical tests. All tests were conducted in duplicate.

For Part II of the study, 26 market-sized eviscerated cod 1 day post mortem were purchased from a local day-boat in June 1984. Two fish were reserved for examination and testing as 0 day reference samples. The remaining fish, after rinsing with tap water, were divided into four groups of six, weighed and put into each of four plastic barrels (32-gallon capacity) containing chilled seawater

(CSW). The fish:seawater:ice ratio in these containers was 3:1.5:1. These barrels were evenly divided into two treatment groups: Group 1 (control) was aerated with purified compressed air, and group 2 was ozonated with gaseous ozone. The barrels were stored at 37°F and daily, for 7 days, the appropriate gas was bubbled for 20 minutes into these barrels through a 12-inch long air stone placed at the bottom of each. Two fish from each group were tested after 0, 1, 4, and 7 days of treatment. After 7 days, the remaining fish were removed from the chilled seawater, stored in flake ice in covered commercial plastic fish boxes, and testing continued during an additional 8 days storage.

The ozone used in this study was produced in a Welsbach Ozonator[1] (Model 408) using purified oxygen as the feed gas. The ozonated water (about 8.0 ppm) was produced by bubbling the gaseous ozone through an air stone into a stream of water flowing through an 18-foot long $1\frac{1}{2}$-inch PVC pipe. To enhance saturation of the water with gas, the pipe was packed with small stones and it contained four U-shaped bends with $\frac{1}{4}$-inch restrictors. It was collected in a covered nalgene carboy containing flake ice and was drawn from a spigot at the bottom of the carboy. The ozonated chunk ice (about 0.6 ppm O_3) was made by chopping blocks of ice prepared by filling polyethylene-lined metal trays (12×42 ×2 inches) with ozonated water and freezing these rapidly in a plate freezer. The procedure for testing the fish in Part II of the study was similar to that followed in Part I.

For sensory analyses, each fish, and subsequently its skinned fillets, was evaluated in the raw state. Examination was made of the following characteristics: 1) General external appearance of the fish, 2) condition of the eyes, 3) appearance and odor of the gills, 4) condition of the muscle, resistance to pressure, gaping, and adherance to the skeletal bone, 5) appearance and odor of the abdominal cavity, 6) color of the muscle—discoloration and blood spots, and 7) odor of the muscle.

The fillets were then steamed in foil-covered pans at 212°F for 15 minutes and evaluated by a 6-member panel of laboratory staff members for appearance. odor, flavor, and texture. Samples were rated on a scale from 1 (inedible) to 9 (excellent). When the average score of any of the above attributes decreased to a value of 5.5 (between fair and borderline) the end of the storage life was considered reached.

To obtain pH, a 20 g sample of fish muscle was blended with 40 ml of distilled water for 1 minute and the pH of the homogenate was measured with a Fisher Model 320 expanded scale pH meter.

Dimethylamine (DMA) and trimethylamine (TMA) analyses were performed by gas chromatography using N-propylamine as the internal standard (Lundstrom and Racicot, 1983). Results are expressed as MgN/100 g muscle.

Thiobarbituric acid (TBA) reactive substances were determined by the method of Yu and Sinnhuber (1957), modified by the addition of disodium ethylenediamine tetracetate (EDTA) and propyl gallate to prevent oxidation during blending. TBA number was calculated by the procedure reported by Sinnhuber and Yu (1958).

The concentration of ozone (O_3) in water and ice was determined by an iodometric method (APHA, 1971). Measured volumes of water and weighed amounts of ice were transferred to 8-ounce jars containing the necessary volume of potassium iodide solution, and the jars were immediately capped. When ice was tested, the jar were set in pans of tepid water to hasten melting. The ozone concentration was measured immediately after melting was complete. Ozonated chunk ice was used in this study because we were unable to measure residual ozone in flake ice which had been prepared from water with an ozone concentration as high as 8.0 ppm. The presence of ozone in the chunk ice was short lived and was not measurable after 24 hours. About 50 percent of the originally measured ozone disappeared after one hour.

The aerobic plate count (APC) was made from appropriate dilutions onto pour plates of TPE agar (Standard Methods Agar reinforced with 0.5 percent Bacto-peptone and 0.5 percent NaCl) as recommended by Lee and Pfeifer (1974) for seafoods. Duplicate plates were incubated at 68°F and colony counts were made after 5 days.

Results and Discussion

The use of ozone in rinse water and/or in ice are procedures which could be used by fishermen aboard vessels or by processors in their plants. The application of ozone to chilled seawater might enable fishermen to sustain high quality in their catches when trips of several days are necessary. It is understandable that if ozonation is to benefit the storage life of fish, the sooner it is applied, the greater will be its advantage. However, its possible benefit to fish of several days post mortem age cannot be discounted as Castell (1953) showed that percentage bacterial reduction on fillets as a result of washing round fish by various means was low for recently caught iced fish and relatively high for fish which had been in ice for several days. Circumstances prevented us from studying fish immediately after their removal from water. Prior to treatment and storage, all fish were examined and judged by raw sensory evaluation to be in excellent condition. For the duration of Part I of the study, no perceptible sensory difference among any of the treatments was noted in the raw whole fish or fillets.

The sensory panel scores (Table 1) of cooked cod treated with ozone in various ways and stored in ice for Part I of this study are shown. There was no significant difference in any of the attributes due to treatments at any time other than at the 9th day if treatment when the controls were significantly lower (1 percent level) in flavor score from the other two treatments. This difference was not maintained so that neither the ozone-rinse nor the ozone-ice appears to extend the panels acceptance of the iced cod. The results of chemical, pH, and bacteriological analyses for Part I of this study are summarized in Table 2.

There was a large deviation in values obtained from fillets of the same treatment for all three amines throughout the study. All treatments showed an increase in TMA content (Fig. 1) after 5 days. After 13 days, the ozone-rinsed fish had a slightly higher content of TMA than the

[1]Mention of trade names on commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

control, while a little less TMA was found in the ozone-iced fish, but differences were not significant.

The DMA content of the cod fillets was low throughout the study (less than 3.9 mgN/100 g for all treatments, but as can be seen from Figure 2, the treatments had no effect on DMA content. Salmon and Le Gall (1936), using either cod or whiting (not stated), did find a lower concentration of TMA and total volatile nitrogen throughout a 12-day storage period in fish stored in ozonated ice compared with ordinary ice. It must be noted, however, that the "ordinary" ice which they used was known to be far from sterile, having a presence of about 25,000 organisms/cc, among which *Pseudomonas fluorescens* were dominant. Fish stored on this nonsterile ice was judged inedible at the 12th day of storage, while those on the sterilized ice were not considered objectionable until the 16th day.

Rancidity did not develop in any of the fish regardless of treatment. All showed a very gradual and very small increase in TBA number throughout the 20 day storage period. Nelson (1982) reported a lower malonaldehyde concentration in fresh Alaskan salmon (pink, coho, sockeye, and silver) stored in ozonated ice compared with regular ice. However, unlike with salmon, rancidity is not a problem with conventionally iced cod and our concern was in whether ozone would cause it to develop. Our results indicate that the very brief contact of the ozone with the fish did not result in oxidation of unsaturated lipid material. It is highly unlikely that the ozone ever contacted fatty acids.

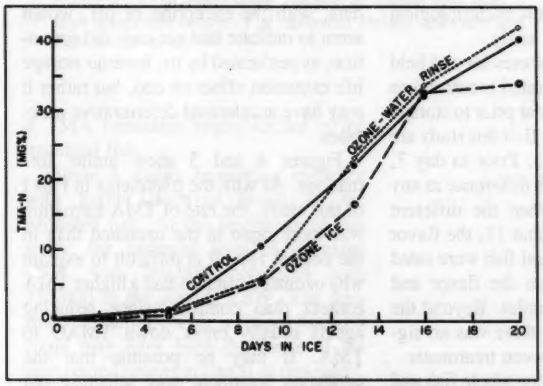

Figure 1.—Trimethylamine content of gutted cod treated with ozone in various manners and stored in ice.

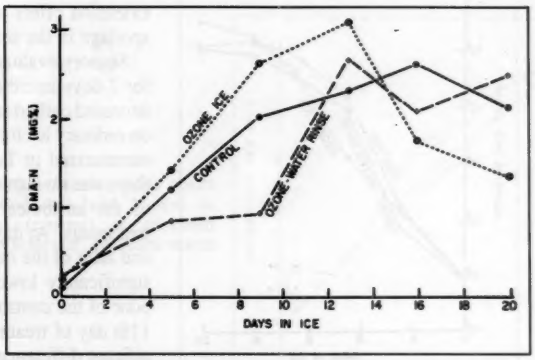

Figure 2.—Dimethylamine content of gutted cod treated with ozone in various manners and stored in ice.

Table 1.—Sensory scores (±SD) for appearance, odor, flavor, and texture of cooked cod treated with ordinary ice (Control), or ozonated water (Rinsed), or ozonated ice (Iced).

Days storage	Treatment	Appearance	Odor	Flavor	Texture
0	Control	8.4±0.8	8.3±0.8	8.5±0.8	7.8±1.3
	Rinsed	8.4±0.8	8.5±0.8	8.5±0.8	8.0±1.1
5	Control	7.7±0.8	7.8±0.8	7.6±0.9	7.7±0.9
	Rinsed	7.8±0.7	7.6±1.0	7.8±0.6	7.7±0.9
	Iced	8.0±0.9	7.8±0.9	7.8±0.7	7.7±0.9
9	Control	6.3±1.1	6.3±1.2	6.3±0.9	6.2±0.9
	Rinsed	7.4±0.5	7.3±0.5	7.1±0.6	6.8±0.9
	Iced	7.1±0.7	7.0±0.7	7.2±0.8	7.2±0.7
13	Control	5.7±1.4	5.4±1.4	6.3±1.6	5.8±1.4
	Rinsed	5.9±1.7	5.5±1.5	5.83±1.0	6.0±1.0
	Iced	5.9±1.8	5.7±1.2	5.4±1.4	5.6±1.2
16	Control	5.4±1.0	4.3±2.2	4.1±2.0	4.5±2.4
	Rinsed	5.9±0.7	4.2±1.9	4.4±2.1	4.6±2.2
	Iced	6.3±1.0	4.2±2.2	4.3±2.1	4.6±2.2
20	Control	5.1±1.4	2.6±1.6	3.5±2.3	3.9±2.2
	Rinsed	4.3±2.2	1.8±0.9	1.3±1.5	3.1±2.0
	Iced	4.0±2.2	1.5±0.8	1.7±1.0	2.7±2.2

Table 2.—Chemical and bacteriological analyses and pH values of cod treated with ordinary ice (Control), an ozonated rinse, (Rinsed), and ozonated ice (Iced).

Days storage	Treatment	TMA (mgN/100g)	DMA (mgN/100g)	TMAO (mgN/100g)	TBA no. (20°C)	APC (20°C)	pH
0	Control	0.18±0.08	0.10±0.06	83.6±0.4	0.50±0.13	$9.4(\pm3)\times10^3$	6.6±0.4
	Rinsed	0.12±0.02	0.25±0.12	85.7±2.4	0.60±0.06	$7.7(\pm8.1)\times10^3$	5.8±0.0
5	Control	1.19±0.53	1.20±0.29	76.2±1.1	0.54±0.0	$187.3(\pm134.0)\times10^3$	6.7±0.0
	Rinsed	1.03±0.73	0.86±0.17	75.2±2.4	0.61±0.09	$72.3(\pm17.1)\times10^3$	6.8±0.1
	Iced	0.67±0.50	1.42±0.95	78.8±6.0	0.62±0.05	$142.1(\pm161.1)\times10^3$	6.6±0.1
9	Control	10.36±6.68	2.01±1.28	59.7±4.7	0.67±0.01	$14.7(\pm1.8)\times10^6$	7.0±0.0
	Rinsed	5.52±5.13	0.93±0.28	71.8±13.4	0.69±0.06	$9.4(\pm5.9)\times10^6$	6.8±0.0
	Iced	5.45±0.77	2.59±1.80	66.9±16.2	0.73±0.0	$1.4(\pm0.2)\times10^6$	6.8±0.0
13	Control	22.8±10.70	2.29±0.44	39.9±28.2	0.59±0.06	$94.5(\pm7.8)\times10^6$	7.0±0.1
	Rinsed	22.88±0.27	2.64±0.35	35.8±11.4	0.54±0.03	$37.5(\pm5.0)\times10^6$	7.0±0.2
	Iced	16.28±10.73	3.04±0.13	51.7±3.0	0.60±0.01	$43.5(\pm0.7)\times10^5$	7.0±0.1
16	Control	31.79±10.91	2.58±0.69	36.1±5.7	0.65±0.08	$146.5(\pm132.2)\times10^6$	7.1±0.3
	Rinsed	33.07±5.9	2.05±0.57	38.0±15.3	0.76±0.06	$80.5(\pm13.4)\times10^6$	6.8±0.1
	Iced	32.13±0.8	1.72±0.08	43.9±3.4	0.72±0.05	$179.5(\pm88.4)\times10^6$	7.0±0.0
20	Control	39.40±11.94	2.07±0.13	19.7±20.9	0.97±0.04	$556(\pm601)\times10^6$	7.2±0.2
	Rinsed	41.27±1.58	2.44±1.32	13.9±8.5	0.81±0.06	$106(\pm36.8)\times10^6$	7.3±0.2
	Iced	33.33±22.37	1.33±0.74	33.2±21.0	0.84±0.05	$332(\pm166)\times10^6$	7.4±0.3

A gradual increase in pH resulted in the iced controls and both of the ozone treated fish. The rate of increase did not vary with the treatment, just as would be expected from the amine production.

Figure 3 shows the results of aerobic plate count. None of the treatments appear to delay an increase in bacterial counts. Salmon and Le Gall (1936) reported a marked decrease in the number of microorganisms observed on the flesh of whiting immediately following an ozonated seawater wash. This difference was not apparent between the ozone-rinsed and control fish in our study; however, the initial aerobic plate counts in our study were low for all of the fish. Unfortunately, Salmon and Le Gall (1936) did not report bacterial counts after storage. In the study with Alaska fresh salmon, Nelson (1982) reported that when the ozone contacted the skin of the fish, the bacterial counts remained in the tens and hundreds of thousands after 8-9 days of storage on ozonated ice while the controls showed counts in the million-plus range. De Witt et al. (1984), in two separate studies with Gulf of Mexico shrimp, reported that storage in ozonated ice had no effect on the bacterial spoilage of shrimp in one study, but could possibly have a 1-2 day storage life extension effect on their bacteriological spoilage in the second study.

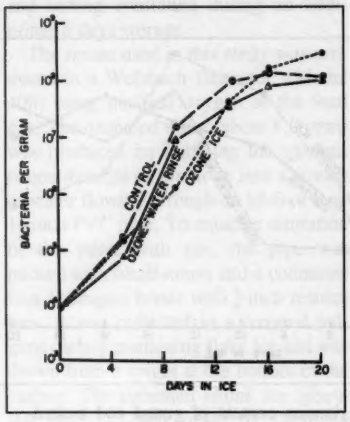

Figure 3.—Aerobic plate count of gutted cod treated with ozone in various manners and stored in ice.

Sensory evaluation scores for cod held for 7 days in either aerated (controls) or ozonated chilled seawater prior to storage on ordinary ice for Part II of this study are summarized in Table 3. Prior to day 7, there was no significant difference in any of the attributes between the different treatments. At days 7 and 11, the flavor and odor of the ozonated fish were rated significantly lower than the flavor and odor of the control samples. Beyond the 11th day of treatment, there was no significant difference between treatments.

Examination of the raw whole fish and fillets did not reveal any differences between the treatments for off-odor development. At day 4, both of the ozonated samples felt less firm and resilient than the control fish; however, this observation did not seem to influence taste panel results. This softness was still noted in the ozonated samples at 7 and 11 days, but it is not clear from taste test results if this influenced panelists' texture scores. At 7 and 11 days, the skin of ozonated cod seemed more faded or bleached than the controls, but observations on the initial color of individual fish were not made and recorded, so this difference may not be actual. Beyond 11 days, there was no obvious differences in the general condition of the whole fish or fillets.

Table 4 summarizes the results of chemical, pH, and bacteriological analyses for Part II of this study. All of these data, with the exception of pH, would seem to indicate that not only did ozonation, as performed by us, have no storage life extension effect on cod, but rather it may have accelerated deteriorative processes.

Figures 4 and 5 show amine formations. As with the treatments in Part I of this study, the rate of TMA formation was more rapid in the ozonated than in the control fish. It is difficult to explain why ozonated samples had a higher TMA content than controls, since reducing agents usually break down TMAO to TMA. It may be possible that the ozonation treatment was selecting out bacterial species that were capable of producing TMA from TMAO. Unfortunately, there was no sampling done between day 1 and day 4, so it is not known

Table 3.—Sensory scores (±SD) for appearance, odor, flavor, and texture of cooked cod treated prior with aerated CSW plus ice (Control) and ozonated CSW plus ice (Ozonated).

Days storage	Treatment	Appearance	Odor	Flavor	Texture
0	Control	8.7±0.7	8.6±0.7	8.1±0.8	8.1±1.1
1	Control	8.8±0.5	8.8±0.4	8.8±0.4	7.8±1.4
	Ozonated	8.8±0.5	8.7±0.5	8.7±0.5	8.3±0.8
4	Control	7.8±0.5	7.7±0.7	7.5±0.7	7.3±1.0
	Ozonated	7.4±0.8	7.7±0.7	7.4±0.7	6.9±1.2
7	Control	7.8±0.5	7.4±0.7	7.3±0.7	7.3±0.7
	Ozonated	6.6±0.7	6.2±1.0	6.2±1.2	6.4±0.5
11	Control	6.0±1.6	6.1±1.2	6.3±1.2	5.3±1.7
	Ozonated	6.3±0.9	4.7±1.2	4.9±1.0	5.8±0.9
13	Control	6.1±0.7	5.4±1.0	5.3±1.0	4.8±1.6
	Ozonated	6.3±0.6	4.2±1.5	4.4±1.6	5.5±1.7
15	Control	5.6±1.3	3.7±2.2	3.8±2.5	4.0±2.3
	Ozonated	5.8±0.9	4.4±1.4	4.7±1.3	5.3±1.2

Table 4.—Chemical and bacteriological analyses and pH values (±SD) of cod treated with aerated CSW plus ice (Control) and ozonated CSW plus ice (Ozonated).

Days storage	Treatment	TMA (mgN/100g)	DMA (mgN/100g)	TMAO (mgN/100g)	TBA no. (20°C)	APC (20°C)	pH
0	Control	0.35±0.33	0.09±0.06	71.8±7.2	0.65±0.05	$7.3(\pm6.0)\times10^3$	6.7±0.3
1	Control	0.12±0.06	0.41±0.52	70.5±21.1	0.71±0.06	$9.2(\pm3.7)\times10^3$	6.8±0.3
	Ozonated	0.30±0.14	0.18±0.06	64.8±1.6	0.88±0.01	$1.7(\pm0.4)\times10^3$	6.7±0.2
4	Control	0.29±0.11	0.46±0.15	70.2±4.2	0.72±0.05	$6.5(\pm1.6)\times10^3$	7.0±0.4
	Ozonated	0.25±0.10	0.56±0.41	66.4±4.2	0.60±0.08	$16.0(\pm4.2)\times10^3$	6.8±0.2
7	Control	2.88±2.23	0.77±0.19	51.3±16.7	0.69±0.06	$118.5(\pm140.7)\times10^3$	6.6±0.0
	Ozonated	15.52±2.76	1.10±0.33	38.2±4.2	0.74±0.01	$606.0(\pm199.4)\times10^3$	7.0±0.3
11	Control	16.20±6.47	1.11±0.54	32.8±7.4	0.85±0.06	$2.0(\pm1.7)\times10^6$	6.9±0.4
	Ozonated	35.03±5.71	1.40±0.12	4.2±4.1	1.05±0.05	$5.3(\pm3.1)\times10^6$	6.7±0.2
11	Control	16.20±6.47	1.11±0.54	32.8±7.4	0.85±0.06	$2.0(\pm1.7)\times10^6$	6.94±0.5
	Ozonated	35.03±5.71	1.40±0.12	4.2±4.1	1.05±0.05	$5.3(\pm3.1)\times10^6$	6.74±0.2
13	Control	10.25±7.92	1.63±0.47	43.8±17.0	0.75±0.0	$8.4(1.5)\times10^6$	7.2±0.0
	Ozonated	42.68±1.92	2.75±1.79	2.4±0.4	0.89±0.0	$22.25(\pm20.9)\times10^6$	7.1±0.2
15	Control	33.44±1.24	1.73±0.14	12.0±7.8	0.62±0.13	$22.1(\pm4.7)\times10^6$	7.1±0.1
	Ozonated	37.42±9.81	1.02±0.26	0.8±0.3	0.80±0.13	$43.0(\pm25.5)\times10^6$	6.9±0.0

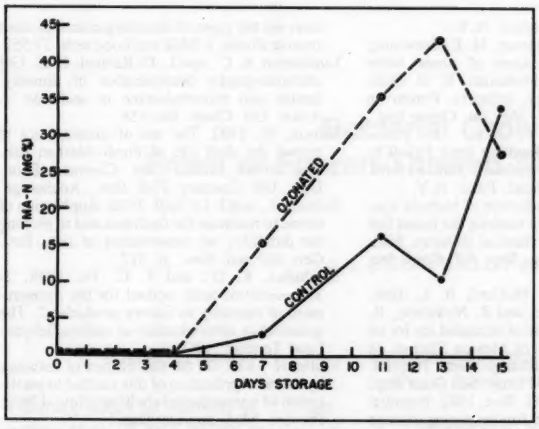

Figure 4.—Trimethylamine content of gutted cod held 7 days in aerated (control) or ozonated chilled seawater and then stored in ice.

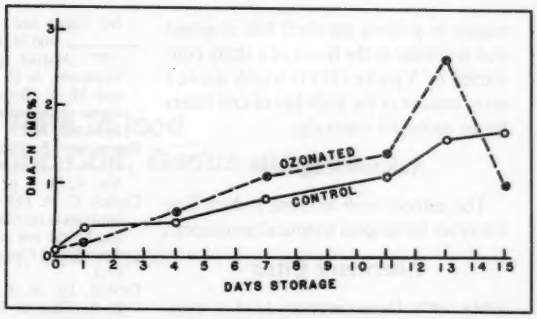

Figure 5.—Dimethylamine content of gutted cod held 7 days in aerated (control) or ozonated chilled seawater, and then stored in ice.

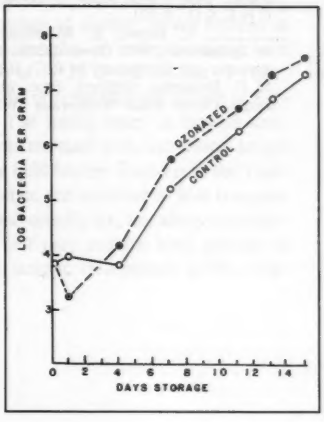

Figure 6.—Aerobic plate count of gutted cod held 7 days in aerated (control) or ozonated chilled seawater, and then stored in ice.

if TMA formation began earlier in the ozonated fish.

Figure 6 shows supporting evidence with higher bacterial levels in the ozonated fish. At the beginning of this study, the bacterial level of ozonated CSW was 260,000 compared with 333,000 in the aerated CSW. The very small reduction in the original bacteria count may have been the cause of the unexpected results in Part II of this study. However, when the ozone concentration of the ozonated CSWwas analyzed and found to be about 5 ppm, we assumed the treatment to be sufficient. Daily determination of the ozone concentration in the CSW immediately following ozonation was attempted, but the bloody, discolored nature of the water made ozone measurement uncertain. On day 7, when the remaining fish were removed from the CSW for storage on ordinary ice, the average bacterial count of the water from the ozonated tanks was 34×10^6ml.

We are unaware of any reported studies of ozonated sea water as a preservation technique; however, Haraguchi et al. (1969) investigated the preservation of jack mackerel, *Trachurus trachurus*, and striped mackerel, *Caranx mertensi*, using ozone in a 3 percent NaCl solution. Although they reported an ozone concentration of only 0.6 ppm, it might be that their contact time between the fish and the ozone exceeded ours, since they ozonated their brine solutions 30-50 minutes before the fish were added and an additional 30-60 minutes after the fish were added. The reported stability of ozone in their brine solution, however, is puzzling. The ozone may have been reacting with one of the components of the seawater to produce a bactericidal ion or compound.

They found initially, that the viable count of bacteria on the surface of the fish dropped to 1×10^{-2} to 1×10^{-3} of the control due to ozone treatment and was delayed about 4 days while decreases in sensory values (raw) were delayed by over one week, lengthening the storage life of the fish 1.2-1.6 times. Their results show, however, that the ozone treatment had little effect on the bacterial count on the muscle of the striped mackerel.

The major disadvantage due to the ozone treatment found by the Japanese investigators was the loss of the fresh-fish smell and the acquisition of a "dried-fish odor" which they attributed to the oxidation of the fish oil by ozone. This would be contrary to results of the Alaska salmon study (Nelson, 1982) where the level of rancidity in the control samples was more than 3 times greater than in the ozone treated samples.

In Part II of our study, as in Part I, rancidity was never detected by taste panelists and TBA numbers remained low (1.0) throughout the storage period. Treatment had no effect on pH changes and those values reported here are normal for iced cod.

The failure of ozone by various tech-

niques to prolong the shelf life of gutted cod is similar to the result of a study conducted by Vyncke (1981) which showed no extension in the shelf life of cod fillets by an ozonated water dip.

Acknowledgment

The authors wish to thank Robert Van Twuyver for helpful technical assistance.

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Bacterial Growth Rate in Iced Fresh or Frozen-Thawed Atlantic Cod, *Gadus morhua*

J. J. LICCIARDELLO and D. L. D'ENTREMONT

Introduction

During times or seasons of fish harvesting gluts, it may be the practice of some processors to freeze the surplus fillets and to defrost at times of scarcity and release for sale in competition with fresh-caught fish. The same situation may also exist with fish that may have been frozen at sea and thawed at port at the end of the trip. The bacterial spoilage pattern and storage life of iced fresh fish is well established (Reay and Shewan, 1949) and familiar to most retailers, but less is known about thawed fish.

Some retailers have expressed concern that thawed fish in ice may have a different spoilage pattern which could affect retail distribution. The prevailing opinion among many retailers, not based on a controlled study, is that the thawed fish would spoil faster. Therefore, it was considered of practical interest to investigate this situation with Atlantic cod, *Gadus morhua*, a species of commercial importance caught in great quantity in the U.S. northeast during certain seasons.

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ABSTRACT—Fillet portions of freshly landed Atlantic cod, Gadus morhua, *were either directly stored in ice or frozen for a brief period, thawed, and then stored in ice to determine and compare subsequent shelf lives so a retailer handling both products could be cognizant of the comparative perishability of both product treatments. The frozen-thawed portions were found to have as long or a slightly longer iced-storage life compared with nonfrozen portions.*

Materials and Methods

Sample Preparation

Eviscerated market-size Atlantic cod of 1-day post mortem age were obtained from a Gloucester processor. The fish were filleted at the NMFS Gloucester Laboratory of the Northeast Fisheries Center in accordance with standard commercial practice; the fillets were halved, and individual portions were sealed in polyethylene bags and coded. Some fish were stored in flake ice for various times prior to filleting, to determine the effect of post mortem age on freezing.

Samples to be frozen were quick frozen in a plate freezer to a center temperature of −18°C (monitored by thermocouple) and subsequently stored for up to 9 months in a walk-in freezer maintained at −18°C (0°F). When required, samples were allowed to thaw overnight by transferring to a refrigerator at 2°C. For iced storage studies, the packaged samples were buried in a container of flake ice and kept refrigerated at 2°C.

Microbiology

Microbiological analyses were made in duplicate on 50 g samples in accordance with methodology outlined in the Bacteriological Analytical Manual (FDA, 1984). Appropriate dilutions were spread-plated on the surface of prepoured agar plates and colonies were counted after 5 days incubation at 20°C. For the aerobic plate count, standard methods agar was fortified with 5 g bacto peptone and 5 g NaCl per liter as recommended by Lee and Pfeifer (1974) for seafoods. For counting *Pseudomonas putrefaciens*, bacto peptone iron agar was used as recommended by Levin (1968).

Results and Discussion

The aerobic plate counts (APC) during iced storage of control (never frozen) or thawed samples of cod previously held frozen at −18°C (0°F) for 1 day, 1 month, or 6 months are shown in Figure 1. The initial count in thawed samples was reduced with increasing length of time held frozen. Bacteria in the vegetative state are sensitive to low temperatures and usually die, not always immediately, but may require long periods of frozen storage (Borgstrom 1955). She-

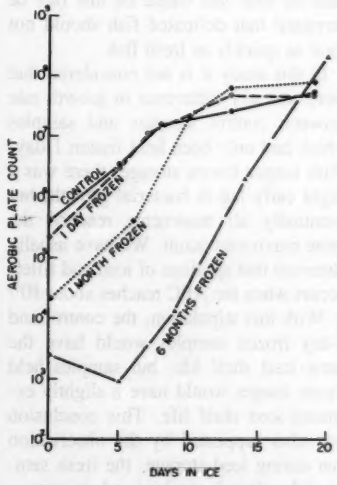

Figure 1.—Aerobic plate counts during iced storage of control or thawed samples of Atlantic cod previously held frozen at −18°C for various times.

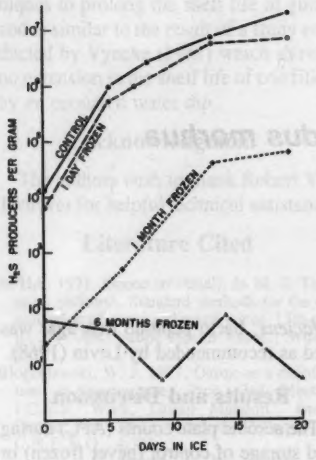

Figure 2.—Bacterial counts of hydrogen sulfide formers (P. putrefaciens) during iced storage of control or thawed samples of Atlantic cod previously held frozen at −18°C for various times.

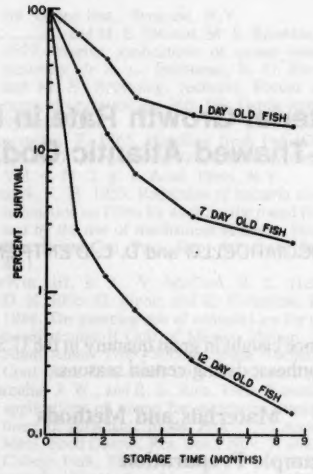

Figure 3.—Percent survival of aerobic bacteria during frozen storage (−18°C) of Atlantic cod at various post mortem ages.

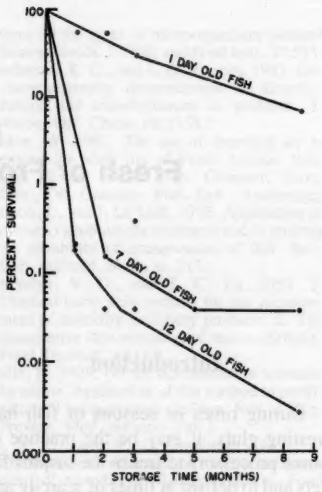

Figure 4.—Percent survival of P. putrefaciens during frozen storage (−18°C) of Atlantic cod at various post mortem ages.

wan (1961) also reported that freezing and cold storage reduced the bacterial load on fish, and based on this fact he surmised that defrosted fish should not spoil as quickly as fresh fish.

In this study it is not considered that there was any difference in growth rate between control samples and samples which had only been held frozen 1 day. With longer frozen storage, there was a slight early lag in bacterial growth, but eventually all treatments reached the same maximum count. We have usually observed that spoilage of iced cod fillets occurs when the APC reaches about 10^6/g. With this stipulation, the control and 1-day frozen samples would have the same iced shelf life, but samples held frozen longer would have a slightly extended iced shelf life. This conclusion was also supported by the observation that during iced storage, the fresh samples developed spoilage odors sooner than the defrosted samples. Other researchers working with Cape hake also found that due to a lowering in bacterial numbers during frozen storage, the frozen-thawed fish had a longer storage life at chill temperatures compared to fresh fish (Simmonds and Lamprecht, 1980).

The growth rates of *Pseudomonas putrefaciens* during iced storage of control or frozen-and-thawed samples can be seen in Figure 2. This particular bacterial species is the principal H_2S producer on fish flesh and is considered to be a major fish spoilage organism because of its proteolytic activity (ability to reduce trimethylamine oxide to trimethylamine, having a fishy odor) and production of hydrogen sulfide (Castell et al., 1949). This microorganism was very sensitive to long-term frozen storage; in thawed samples held frozen for 6 months, there was no growth during iced storage.

The effect of frozen storage time at −18°C on survival of the aerobic bacteria on cod is shown in Figure 3 for 1, 7, or 12 days post mortem age prior to freezing. The survival curves indicated that the older the fish at the time of freezing, the greater the reduction in bacterial numbers during frozen storage. This could be due to a quantitative change in the microbial flora during post mortem iced storage with a predominance of more freeze-sensitive cells in the older fish. There also was a greater rate of inactivation during the first few months of frozen storage. The more freeze-sensitive cells in the flora probably died off first. From these results one might surmise that keeping fish frozen for an extended time prior to thawing and storing in ice might be an effective way of reducing the bacterial load and thus increase subsequent iced storage life. However, Reay (1935) reported that the course of bacterial decomposition in iced fresh or thawed haddock (previously held frozen at −21°C) was the same, but physical-chemical changes (oxidative rancidity and textural toughening) during extended frozen storage impaired the quality of the thawed fish during subsequent iced storage.

The fate of *Pseudomonas putrefaciens* during frozen storage of cod of various post-mortem ages (Fig. 4) was similar to that of the aerobic plate count; that is, the older the fish at time of freezing, the greater the rate of inactivation. However, *Pseudomonas* was more readily inactivated during frozen storage. For example, after 2 months, the percent survival was about 0.1 for the *P. putrefaciens* and 4.0 for the total aerobes when comparing the averages of 7- and 12-day-old fish. Reduction in numbers of these major fish

spoilage bacteria during frozen storage may have played a principal role in the extended iced shelf life of the thawed samples.

Conclusions

The aerobic bacterial count of cod fillet portions was reduced during frozen storage at −18°C, a greater reduction occurring with increasing storage time. The older (staler) the fish at time of freezing, the greater the reduction in bacterial numbers during frozen storage. *Pseudomonas putrefaciens*, a major fish spoilage bacteria, was readily inactivated during frozen storage. The iced shelf life of frozen-and-thawed cod compared with fresh cod was similar or extended depending on length of frozen storage.

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On-Board Handling and Preservation of Frozen Troll-Caught Albacore, *Thunnus alalunga*

DONNA R. JACOBY

Introduction

There has been a steady decline in the cannery market demand for U.S.-caught albacore, *Thunnus alalunga*, in the past few years due to a shift from domestic to overseas canneries (Herrick and Koplin[1], King and Bateman[2], Talley[3]). With the reduction of local cannery market orders, the U.S. west coast albacore fishery is forced to seek alternative markets. This has led to an emphasis on fresh marketing and to an increased demand for high quality standards for both the fresh and frozen product (Pleschner[4]). It is important to the development of new markets that the product delivered to the consumers be of a high and consistent quality.

Bleeding and evisceration of fish is essential in the U.S. salmon fishery to maximize fish flesh quality (Melvin et al., 1983), and is required in the foreign tuna-sashimi market (Gibson, 1984).

Although studies have suggested that bleeding and evisceration is necessary for a high quality product (Amos, 1981, Merritt, 1969; Reay and Shewan, 1960), the effects of bleeding and evisceration on the quality of frozen albacore has not been shown.

The objective of this study was to compare the effects of three different handling methods and four different freezing systems on the quality of frozen albacore. Quality was quantitatively compared using bacterial, sodium, and moisture analyses. Selected qualitative, physical, and sensory changes that occur over time while held in standard fresh market storage conditions were evaluated by sensory panel judging.

[1]Herrick, S. F., Jr., and S. J. Koplin. 1985. U.S. tuna trade summary, 1984. NMFS Admin. Rep. SWR-85-6:1-24.
[2]King, D. M., and H. A. Bateman. 1985. The economic impact of recent changes in the U.S. tuna industry. Calif. Sea Grant Coll. Program Work. Pap. P-T-47:1-30.
[3]Talley, K. 1985. Tuna update. Pac. Fish. VI(3):35.

ABSTRACT—Techniques of bleeding, eviscerating, and shipboard freezing of albacore, Thunnus alalunga, *immediately after landing, to enhance the quality of the frozen product were investigated. Analytical tests used to evaluate the quality of the fish were aerobic plate counts and sodium and moisture analyses. Sensory changes that occur over time while held in standard fresh market storage conditions were evaluated by a sensory panel. The body temperatures of both bled and eviscerated fish decreased faster than nonbled fish. Brine immersion followed by transfer to coil refrigeration resulted in the lowest bacterial growth for all handling methods. Neither handling treatments nor preservation methods had any significant effect on sodium or moisture concentrations. Sensory judging found little difference between handling methods. Discoloration due to oxidation of the oils was the major objection to acceptability of quality.*

Methods and Materials

Albacore were collected aboard commercial jig boats in the eastern Pacific Ocean off central California. A total of 57 albacore, ranging from 4.2 to 10.5 kg, were collected.

The body temperature of each albacore was measured immediately after capture using 4-inch probe thermometers that were calibrated with a mercury thermometer at the beginning of each fishing trip. Temperatures were taken deep in the lateral muscle behind the pectoral fin, where the highest body temperature is found (Carey and Teal, 1966).

Handling methods investigated were: 1) Traditional—these fish were whole, neither bled nor eviscerated; 2) Bled—these fish were bled immediately after first temperature measurement by cutting the afferent branchial artery at the bottom of the gills; and 3) Bled, gilled, and eviscerated—these fish were bled, as above, then gilled and eviscerated after bleeding was completed. Gills were severed at their points of attachment. Then, the membrane behind the gills was severed and the viscera were all pulled out attached to the gills. Evisceration without cutting the belly open minimizes contamination and maintains the external appearance of these fish. The fish were then washed, and any remaining kidney, loose membranes, or tendons were removed.

Deep-body temperatures were measured after bleeding and again after evisceration. Temperatures were then measured at 1-hour intervals for 2 hours, after which the fish were frozen. Body temperature decreases over time were analyzed for significance using the one-way analysis of variance test (Zar, 1974).

Four methods of freezing were investigated. These, and their temperature ranges, were: 1) Spray brine (−7.8 to −6.7°C); 2) coil refrigeration (−4.4 to −3.3°C); 3) chilled brine (−17.8 to −15.0°C) until frozen (3-6 hours), then

[4]Pleshner, D. B. 1985. Pacific albacore, handle with pride. Pac. Fish. VI(7):28-36.

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transfer to coil refrigeration (−4.4 to −3.3°C); and 4) air blast (−17.8 to −15.0°C).

Upon returning to port, specimens were unloaded, bagged, boxed, and stored in a local fish processor's air-blast freezer maintained at −30 ± 4°C until analyses were performed.

Analytical Tests

Muscle tissue samples were aseptically removed from the mid-dorsal loin area at the origin of the first dorsal fin. After removing the skin, samples were drilled from frozen specimens using sterile 1/2-inch diameter, hollow, stainless-steel core bits. Samples included the tissue from just underneath the skin down to the spinal vertebrae. Samples were kept frozen at −12°C until laboratory analysis. Each sample was homogenized before analysis. All analyses were performed by Soil Control Lab[5], Watsonville, Calif.

Aerobic plate counts were done as follows: 10 g of muscle tissue were blended with 10 ml of sterile 0.1 percent peptone water for 2 minutes and spread-plated on Standard Methods Agar with 0.5 percent NaCl added. They were then incubated for 4 days at 20°C. This follows the methodology for marine finfish as suggested by Liston and Matches (1976).

For sodium and moisture analysis, 1 g of tissue sample was dried to constant weight, which provided moisture content data. The sodium content was then measured on a dry weight basis by atomic absorption spectrometry.

The data from the aerobic plate counts and sodium and moisture analyses were analyzed for significance using the Kruskal-Wallis test, a nonparametric two-way analysis of variance (Conover, 1980). For all statistical tests, significance level was set at $\alpha = 0.05$.

Sensory Analysis

Sensory comparisons were made of two handling methods: 1) Traditional (non-bled) fish; and 2) bled, gilled, and eviscerated fish.

Samples were prepared by cutting the frozen specimens into steaks with a meat-cutting bandsaw. The steaks were placed into plastic pouches, labeled and returned to the freezer until needed. Each day one steak from each method was defrosted and placed in a local fish market's cool storage room which was maintained at a temperature of 0.5°C. Steaks were assessed on a total of 12 consecutive days.

Sensory assessments of the steaks were made by a trained panel of six judges. The samples were presented to the panelists in the raw state as one would view them in a fresh fish market. Panel members were trained by observing the spoilage pattern of albacore over its shelf life by the use of labeled samples. The panelists judged duplicate sets of each method. Duplicate sets were made by slicing each steak in half so that each sample contained both dorsal and ventral portions of the steak. This avoided any difference between sets. Each handling method and set was judged separately.

Panelists judged for odor and visual appearance, and were allowed to touch the steaks to feel for oil and moisture content differences. The judges estimated the amount of time each fish steak had been stored under refrigeration and indicated their acceptance or rejection of its quality (Fig. 1). Expressing the quality of

Raw Evaluation - Albacore

Use odor as the primary basis of judgment. Use appearance as a deciding factor in borderline cases only.

Quality descriptors	Your estimate of time sample was refrigerated (1-12 days)	Sample Letter	Acceptance: Would you cook & eat this fish?	
			YES	NO
Sea-fresh, seaweedy, briny, neutral, or little odor. Glossy or translucent appearance.				
Little odor or very slight fishy, stale or musty odor. Little or no glossiness.				
Slight fishy, sour, or acidic odors. Somewhat dull waxy or opaque. Some discoloration.				
Definite fishy, rancid, sour, or acidic odors. Opaque with moderate discoloration.				
Very strong fishy and rancid odors. Opaque, and dry with much discoloration.				

Figure 1.—Sensory evaluation data sheet.

[5]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

the product in terms of estimated storage time is an approach developed by Learson and Ronsivalli (1969).

Panelists' duplicate evaluations were compared using scatter plots to check the consistency of their answers and their ability to judge the spoilage pattern of albacore. For statistical analysis, the data were entered into a contingency table and analyzed using the chi-square statistic (Zar, 1974).

Table 1.—Decrease of body temperature over time of freshly caught albacore handled three different ways. Ten fish were measured for each handling method.

Handling method	Mean temperature loss (°C ± S.D.) and Time elapsed since fish landed		
	15 min.	1 hour	2 hours
Traditional		2.9±1.92	3.7±1.92
Bled	1.3±0.87	3.5±1.15	5.6±1.45
Bled, gilled & evisc.	1.5±0.83	3.6±1.06	5.1±1.29

Results

The mean deep-body temperature losses of 10 specimens from each handling treatment (N = 30) were higher for bled, and bled, gilled, and eviscerated fish than traditionally handled fish, but not in a statistically significant way (Table 1). By 2 hours after bleeding, the differences were higher but were not significant ($P = 0.06$).

Analytical Tests

Aerobic plate counts ranged from less than 1.0×10^3 to 1.8×10^5 colony-forming units/g (Table 2). Significant differences were found among both handling methods and freezing systems ($P = 0.02$). The brine tank/coils freezing treatment consistently resulted in the lowest bacterial growth for all three handling methods. The only significant difference between handling methods for any one freezing system was in air blast where the traditional fish had significantly lower bacterial counts than the bled, gilled, and eviscerated fish, but the meaning of this result is unclear due to the large differences in variances in the two treatments. The counts for the traditional treatment exhibited very low variability while those for the other two treatments were quite variable.

Every albacore sampled had relatively low bacterial counts. The count on the raw material can be expected to be between 10^4 and 10^6 bacteria/g on arrival at the processing plant. Counts on good quality material held under good conditions range from 10^4 to 10^5 bacteria/g (Liston and Matches, 1976).

Neither handling treatments nor preservation methods had any significant effect on sodium concentrations (Table 3). The values ranged from 875 to 3400 ppm. There were no consistent trends.

Similarly, handling treatments and freezing methods had no significant effect on moisture content (Table 4). Values ranged from 57.8 to 77.2 percent. Although not significantly so, fish frozen

Table 2.—Aerobic plate counts of albacore dorsal muscle tissue for 3 different handling methods and 4 different freezing systems; mean values are for colony forming units per gram[1].

Handling method	Mean APC values			
	Spray brine	Brine tank/coils	Coils only	Air blast
Traditional	$8.0\times10^{4**}$	$3.2\times10^{3*}$	4.5×10^{4}	$2.5\times10^{3*}$
Bled	2.3×10^{4}	$4.2\times10^{3*}$	1.1×10^{4}	$6.4\times10^{4**}$
Bled, gilled & eviscerated	$4.5\times10^{4**}$	$1.0\times10^{3*}$	1.9×10^{4}	4.2×10^{4}

[1]Means within the same horizontal row followed by * have significantly lower bacterial counts than those followed by **

Table 3.—Sodium content (dry-weight basis) in the dorsal muscle of albacore; mean values are expressed as parts per million/g.

Handling method	Sodium content			
	Spray brine	Brine tank/coils	Coils only	Air blast
Traditional	1,630 ± 214	1,409 ± 580	1,930 ± 676	2,140 ± 723
Bled	1,680 ± 498	2,202 ± 811	2,258 ± 741	1,948 ± 466
Bled, gilled & eviscerated	2,463 ± 783	2,032 ± 241	2,038 ± 509	2,144 ± 532

Table 4.—Moisture content (%) in the dorsal muscle tissue of albacore for 3 different handling methods and 4 different freezing systems. Values given are means followed by standard deviations.

Handling method	Moisture content			
	Spray brine	Brine tank/coils	Coils only	Air blast
Traditional	68.5 ± 0.3	66.5 ± 2.1	70.1 ± 1.9	66.1 ± 5.1
Bled	66.7 ± 0.6	66.9 ± 2.0	70.8 ± 4.7	67.2 ± 6.3
Bled, gilled & eviscerated	66.3 ± 1.5	67.1 ± 4.4	69.3 ± 4.4	68.2 ± 4.0

Neither handling treatments nor preservation methods had any significant effect on sodium concentrations (Table 3). The values ranged from 875 to 3400 ppm. There were no consistent trends.

Similarly, handling treatments and freezing methods had no significant effect on moisture content (Table 4). Values ranged from 57.8 to 77.2 percent. Although not significantly so, fish frozen

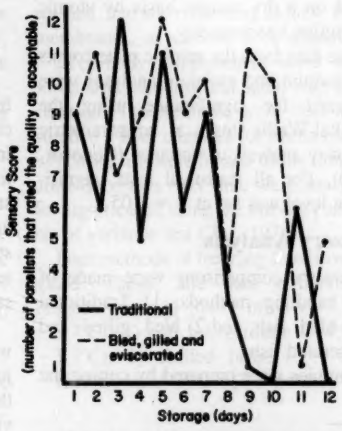

Figure 2.—Sensory evaluation of albacore steaks.

by the "coils only" method had a higher moisture content than the other freezing methods, regardless of handling method.

Sensory Analysis

There were no statistically significant differences between the two handling treatments in the sensory analysis. However, bled, gilled, and eviscerated fish generally had higher acceptability counts and were acceptable for a longer period of time than traditionally handled fish (Fig. 2). Discoloration—browning of the flesh—started by day 6 and was well developed by day 8. Even though discoloration had begun, there was a lag time of several days before the off-odors associated with spoilage occurred. Moisture loss also contributed to rejected acceptability starting at day 8.

Discussion

Fish spoils mainly through bacterial decomposition. Enyzmes also play a part in decomposition, either directly or by providing the bacteria with readily assimilable nutrients. It has been shown that temperature is the most important single factor affecting spoilage rate (Reay and Shewan, 1960). Research on raw albacore kept at temperatures above freezing has shown that bacterial growth is dependent on the storage temperature (Farber and Lerke, 1961).

The marine bacteria responsible for spoiling marine fish are of the psychrotrophic variety, which exhibit their most rapid population increases between 20° and 24°C (Reay and Shewan, 1960; Liston and Matches, 1976). All varieties of bacteria build up populations more slowly the lower the temperature is below optimum, but marine bacteria continue to multiply under chill conditions. Some remain active, even in frozen fish. The temperature must be below −10°C before bacteria cease to grow and multiply (Amos, 1981).

Enzymes, the compounds responsible for digestion and cell metabolism, will remain active even in dead fish. These chemical reactions are slowed down by chilling the fish. However, an increase in chemical activity will occur just below the point at which freezing of the flesh begins, in the region of −1° to −5°C (Merritt, 1969). This is caused by the fresh water in the fish flesh freezing, thereby concentrating the enzymes. The more slowly the fish are frozen the larger the ice crystal formation will be, and large ice crystal formation causes the membranes in the fish flesh to break, providing greater potential for enzymatic decay and texture loss. Keeping the fish below −5°C causes the chemical activity to slow down dramatically. However, the fish would have to be chilled to −30°C to bring a halt to chemical spoilage (Amos, 1981).

Albacore are a warm-bodied fish, capable of achieving muscle tissue temperatures that are 12°-14°C warmer than the ambient surface water temperature (Carey et al., 1971; Konagaya et al., 1969). This is due to a countercurrent heat exchange system consisting of a rete of closely packed arteries and veins located in the vascular system of the lateral muscle. This rete provides a thermal barrier preventing heat generated by metabolism from being lost to the colder, surrounding water, when the blood passes through the gills (Carey and Teal, 1966). The high temperature of albacore when landed (26°-30°C) increases the initial rate of chemical reaction and enzymatic activity and as a result starts the decrease of the flesh quality before it is subjected to refrigeration and during the substantial amount of time it takes to freeze these large fish. Laurs et al. (1978) estimated that the total blood volume of albacore comprised 8.2-19.7 percent of the body weight of the fish. I had hoped to show that bleeding was an effective way to immediately decrease body temperature and perhaps with more samples it would have. Although bleeding did not prove to be statistically significant, it is considered a good practice since it removes heme compounds which accelerate oxidative rancidity (Ronsivalli, 1982), and results in a lighter colored flesh (Amos, 1981; Ronsivalli, 1982).

Frozen albacore varies in sodium content because of harvesting and processing practices. The two methods of preservation that contribute most to variable sodium content in albacore are brine freezing, either by continuous spray-brine or the immersion in chilled brine before transfer to the coil freezer. Brine freezing is the most commonly used method of preservation in the tuna fishery (Wekell et al., 1983). Since fish are hypo-osmotic to the brine solution, they will tend to take up salt or sodium into their tissues. The amount of sodium incorporated depends on storage time, temperature of the brine, the size of the fish, and the amount of time it takes to freeeze them (Farber, 1955; Roach et al., 1967; Tomlinson and Geiger, 1963). During the freezing process, penetration of sodium into the outer 3/8-inch of flesh can be quite high, but is insignificant into the inner layers of the flesh (Roach et al., 1967; Tomlinson and Geiger, 1963; Tomlinson et al.[6]). This is why each sample was homogenized before analysis.

Fish are added to the fish holds on an "as caught basis" and since this increases the temperature of the hold at least temporarily, sodium penetration to each fish is erratic. Other factors to take into consideration are the capacity and reliability of the refrigeration system, and the location of the fish in the fish hold. Where two fish freeze close together, salt penetration will be greater in the sides exposed to the brine than in the sides touching each other. It has been shown that low temperatures must be used, (ideally −18°C), to prevent any appreciable salt penetration into the flesh during freezing and storage in strong brine solutions (Farber, 1955).

Although there has been much recent discussion of the suitability of spray-brined fish for the fresh and frozen market, I found no significant quality degradation in the spray-brined fish. However, Ronsivalli and Baker (1981) reported that absorption of salt has a catalytic effect in oxidative deterioration of the quality of the fish during subsequent storage. It should also be mentioned that the fish in this study were stored from only 2 days to 2 weeks in the freezers aboard the fishing vessels. This is an unusually short time and could account for the variability in the data and the similarity among freezing systems.

[6]Tomlinson, N., S. E. Geiger, and E. Roberts. 1962. Frozen albacore tuna: the influence of storage conditions prior to freezing. Fish. Res. Board Can., Pac. Coast Sta. Prog. Rep. 114:

In oily fish such as albacore, the oxidation of the oil can contribute significantly to spoilage. Fish oils of the unsaturated type readily combine with atmospheric oxygen, with the assistance of catalysts in the flesh, which causes rancid odors and flavor and color changes (Reay and Shewan, 1960). It was mainly the browning of the flesh that caused sensory judges to reject samples. This would not have been as apparent had the samples been cooked, although the cooking procedure (baking, steaming, frying) chosen for panel testing can affect the results (Dyer et al., 1964).

Conclusion

This study has shown that albacore preserves as well with a minimum of handling and is amenable to any short-term freezing technique that ensures consistent temperatures below freezing. The fish that were obtained for this study were of a consistently high quality. This could be attributed to the fact that the fishermen who volunteered their time and effort to collect the specimens and record temperature and handling data were already very quality-conscious. It should also be noted that due to the nature and amount of work involved in on-board sampling, the project fish were collected on slow fishing days when time was available and the freezer systems were not stressed. Perhaps the absence of any significant differences between handling treatments indicated that the quality of troll-caught albacore is a result of effort on the part of the fishermen along with adequate refrigeration equipment, rather than any specific handling technique or refrigeration technology.

It is recommended that the fish should be frozen as rapidly as possible and that once frozen they not undergo large temperature fluctuations which lead to periods of thawing and refreezing.

Acknowledgments

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Light Transmission as a Criterion for Sorting Pacific Herring, *Clupea harengus pallasi*, by Sex

A. KHAIRULLAH, R. PAUL SINGH, and P. CHEN

Introduction

Electro-optical techniques are commonly employed in the food processing industries to sort products based on their optical properties. Although these techniques are widely used in the food industries for mechanical sorting of fruits and vegetables and for quality evaluation (Powers et al., 1953; Chen, 1979), their use in sorting fishes has been limited. A major reason for this is the lack of data on physical properties of fish and other seafoods.

In fish processing plants, many of the fishes processed contain eggs, which are subsequently wasted during processing. If eggs present in the female fishes were removed before processing, they could be utilized as caviar, thereby enabling profitable use of otherwise wasted material.

A Canadian company[1] (Techwest Enterprises Ltd, Westbrook Crescent, Vancouver, BC, V6S 2L2) attempted to manufacture a commercial sex sorting device for herring in middle 1970's. The design of their machine involved the use of optical properties of herring for sex separation. Although there was a limited success in meeting the objectives with a laboratory apparatus, an industrial-scale unit did not function well in a plant environment, and it is believed that the company abandoned the project. There is no published information available on optical properties of herring that will be useful in design and operation of a sex sorting machine at industrial-scale efficiencies.

We used transmission of light to investigate the possibilities of sorting male and female Pacific herring, *Clupea harengus pallasi*. We used fresh samples of herring held on ice for not more than 3-4 days. The objectives of this study were to 1) investigate the light transmittance through the bodies of the male and female herring subjected to incident light of varying wavelength (400-800 nm) and 2) develop a conceptual design of an apparatus for sorting herring based on the optical properties.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

ABSTRACT—The effect of light transmission through the body of Pacific herring, Clupea harengus pallasi, *was investigated. With the use of a high-density spectrophotometer and a special fiber optics attachment, male and female herring were subjected to light transmission in the wavelength range of 400-800 nm. Males differed significantly from females in transmission response. Thus, light transmission may be used as a criterion for sorting these fishes by sex. An industrial application of a sorting device has been suggested, based on the results.*

Theory

Optical properties, such as reflectance, transmittance, absorption, or emission can be used to obtain information on other characteristics of a product. Only a small fraction of light incident on a solid material gets transmitted through the body (from about 10^{-3} to 10^{-8} of the incident light). This varies with the wavelength of the light beam. A common unit of measurement of transmittance is optical density (OD) defined as:

$$OD = \log_{10}(I_1/I_2)$$

in which I_1 = incident radiant energy and
I_2 = radiant energy transmitted through the sample.

Transmittance (T) is loosely defined as:

$$T = I_2/I_1.$$

The optical density of a sample can be obtained by comparing the spectral transmittance of the sample with that of a set of neutral density filters.

Experimental Procedures

Light transmission was measured with a high-density transmission spectrophotometer, custom built at the Agricultural Engineering Department at the University of California, Davis. The main parts of the instrument are: 1) A monochrometer with lamp, 2) a wavelength drive unit, 3) a detector for transmitted light coming through the sample, 4) a refrigerated housing for the detector, and 5) associated electronics that enable the transmitted light to be plotted graphically on an X-Y plotter. Figure 1 shows a block diagram of the spectrophotometer.

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The monochrometer with lamp and the wavelength drive unit enable transmission of light with continuous variation in wavelength from 400 to 800 nm. The lamp is a 32-candle-power 6.1-volt lamp with a tungsten filament. The monochrometer uses a diffraction grating in the visible spectrum. The light entrance and exit slits from the monochrometer vary from 0.0 to 6.0 mm, and the scale is graduated in 1 mm intervals. The monochrometer wavelength dial is driven by a 0.5 r.p.m. motor which drives the dial from the lower to the higher wavelengths.

The detector system consists of a highly sensitive photomultiplier tube. This is necessary because transmitted light has a very low intensity. The system employs an anode current regulation system, and the output signal is determined by a change in voltage across the dynode string in order to maintain constant anode current. To increase the sensitivity and stabilize the dark-condition voltage, a refrigerated photomultiplier housing is used to maintain a constant low temperature. A shutter is used in front of the photomultiplier tube to prevent excess light from entering the photo cathode area of the tube. The shutter is activated electronically and is always kept open when fiber optics are used with the instrument. Thus it was imperative during the experiments to prevent any undesirable or external light from filtering through to the detector. The output from the photomultiplier tube is connected via an electrical circuit to an X-Y plotter, which converts the detected signal to a graphic form.

The instrument was calibrated before the start of the experiment. Neutral density filters of known optical densities were used for the calibration. Transmittance curves for wavelengths ranging from 400 to 800 nm were plotted for optical density ranging from 5 to 8 OD at increments of 0.5 OD. Transmittance charts obtained for a tested sample can be compared with the calibration OD curves to determine the percent transmittance through the sample (Chen and Nattuvetty, 1980). Using this technique, subsequent transmittance charts obtained for the fish samples, were compared with these OD curves to determine the percent transmittance through the body of each fish at each wavelength. Figure 2 shows typical output curves from the experiment with calibration lines from 5 to 8 OD.

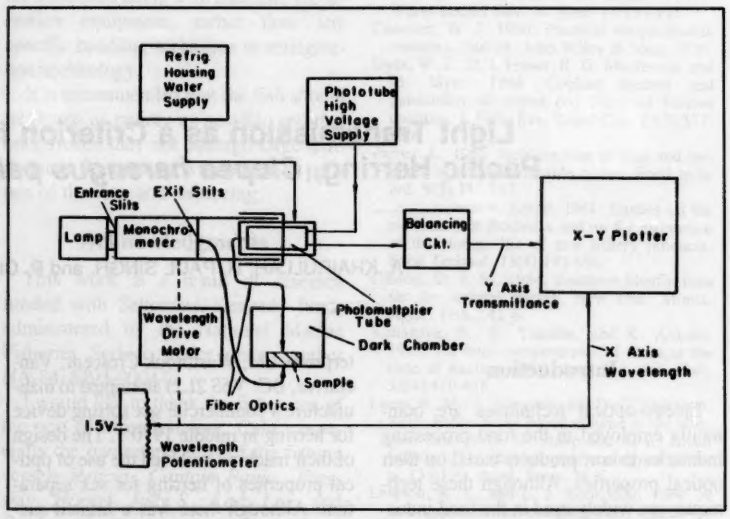

Figure 1.—Block diagram of high density transmission spectrophotometer.

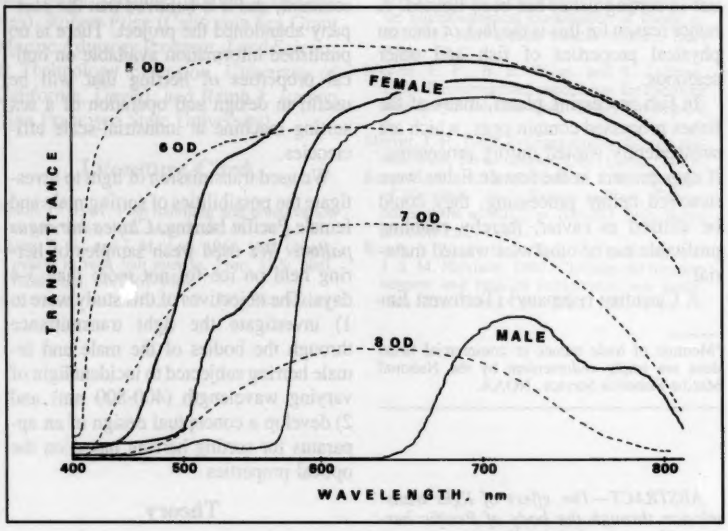

Figure 2.—Typical output curves from the experiment.

A major problem was designing the support for holding each fish as it is subjected to light transmission. Because the detector is very sensitive, the support had to avoid bypass of light. With the use of

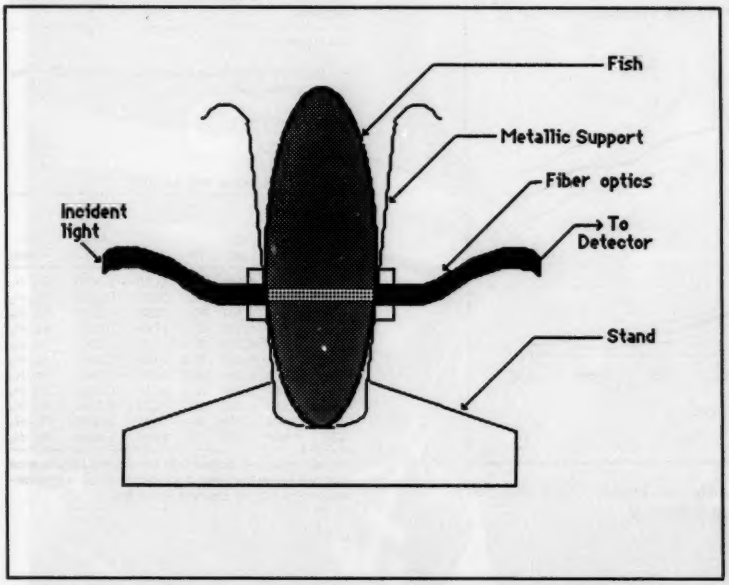

Figure 3.—Cross-sectional view of the support used for the experiment.

fiber optics and a specially designed support (Figure 3), it was possible to eliminate all light bypass. The fiber optics were placed just below the dorsal fin of the fishes to lend uniformity to the experiment. The support was designed to fit the smallest fish in the sample; because the portion of the fish below the dorsal fin is soft and pliable, larger fishes can be squeezed in without any damage to their internal organs. To minimize the influence of ambient light, the spectral scanning was done with the sample and support kept in a wooden housing. Both the support and the wooden housing were sprayed with lampblack to avoid light reflection within the closed chamber.

Results and Discussion

Transmittance curves on about 80 fishes were collected, with each graph having 4 curves. Then each graph was compared manually with the calibration curves to determine the OD readings of the responses at chosen wavelengths. The information from the charts was thus digitized. The intervals between the wavelengths chosen were decided based on the rate of change in response within a certain wavelength band. Smaller intervals were chosen between wavelengths when the change in response was very rapid. At each of the chosen wavelengths, two sets of data points were collected, one set each for male and female fishes.

For the optical density range chosen (5-8 OD), the female typically started showing a response at wavelengths as low as 400 nm. Starting from a reading of about 7.6 OD at a wavelength of 450 nm, there was a continuing decrease in the OD reading of the female species up to about 5.1 OD at 800 nm. This means that transmittance in the female increases as the wavelength increases, with the rate of increase varyng with wavelength. There was a sharp increase in transmittance in the wavelength range of 450-525 nm and again at 550-600 nm. From 600 to 800 nm, the OD increase was comparatively smaller, between 5 and 6 OD.

Below 600 nm wavelength, the male showed little or no response within the OD range chosen. Between 600 and 650 nm, there was a detectable transmittance through the male fishes, but it was of a small order of magnitude and lay beyond the scale (more than 8 OD). Thus it could not be measured. From 650 to 800 nm there was a steady decrease in the OD reading of the male, ranging from about 7.7 OD at 650 nm to about 6.8 OD at 800 nm. Again, this means that transmittance in the male also increases with increasing wavelength.

At each of the chosen wavelengths, a Student's *t*-test estimation of the mean response of each species was performed with a 99.9 percent confidence interval. The results were then plotted on a graph (Fig. 4) drawn using the calibration curves. There was no overlapping of the confidence intervals of the mean responses of the two species, and there was a significant separation between the two means. For example, at a wavelength of 675 nm, the mean OD reading for the female was 5.33 and that for the male was 7.60. At this wavelength, with a confidence level of 99.9 percent, the optical density of the male is expected to be greater than 7.07 nm and that of the female is expected to be less than 5.45. Therefore, at 675 nm, the amount of light expected to pass through the least transparent female will be 42 times the amount of light expected to pass through the most transparent male. At 750 nm the difference in transmittance is expected to be 41 times and at 800 nm it is expected to be 20.5 times.

Again, at each of the chosen wavelengths, a null hypothesis that the mean OD of the male is equal to that of the female was rejected at an extremely high level of significance (0.001) in preference for an alternate hypothesis that the OD of the male is greater than that of the female. The results of the test are presented in Table 1. This just corroborates our earlier findings that the male herrings differ in transmission from female herring fishes.

Suggestions for a Commercial-scale Sorting Device

The above results show that the male has a less translucent body in the range of wavelength inspected and therefore

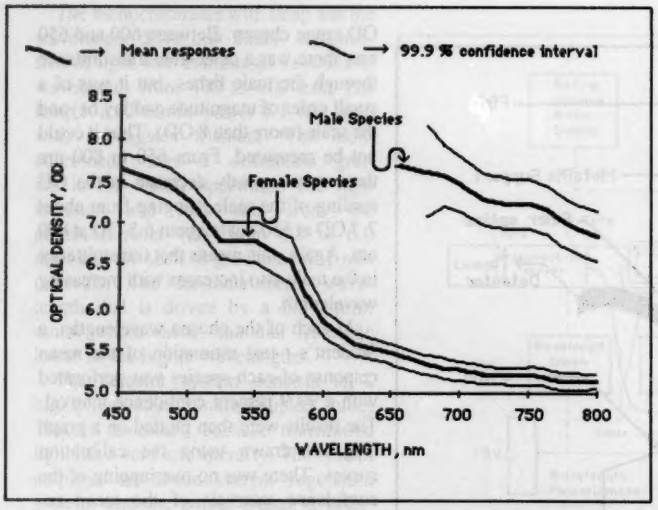

Figure 4.—Mean response of the male and female fishes with 99.9 percent confidence interval.

Table 1.—Test of hypothesis about the difference between the mean transmittance of the male and female herrings[1].

Null hypothesis:

H_o: Mean OD of the male species, μ_M = Mean OD of the female species, μ_F.

Alternate hypothesis:

H_1: $\mu_M > \mu_F$.

Level of significance of test, $\alpha = 0.001$

Wavelength (nm)	μ_M OD	μ_F OD	DF	t	Observed signif. level (P)	Conclusion
800	6.838	5.149	25.4	21.55	0.0000	Rej. H_o
787.5	6.905	5.134	26.1	22.02	0.0000	Rej. H_o
775	7.011	5.143	26.1	22.92	0.0000	Rej. H_o
762.5	7.158	5.179	26.9	24.63	0.0000	Rej. H_o
750	7.229	5.211	26.8	24.23	0.0000	Rej. H_o
734	7.221	5.208	25.9	23.89	0.0000	Rej. H_o
717	7.273	5.220	26.2	23.99	0.0000	Rej. H_o
700	7.447	5.264	25.5	24.51	0.0000	Rej. H_o
687.5	7.547	5.290	23.1	23.34	0.0000	Rej. H_o
675	7.598	5.333	13.8	17.84	0.0000	Rej. H_o
650	7.692	5.466	5.5	13.93	0.0000	Rej. H_o

[1]In each case, α is greater than the observed significance level and hence this leads to a rejection of the null hypothesis in favour of the alternate hypothesis.

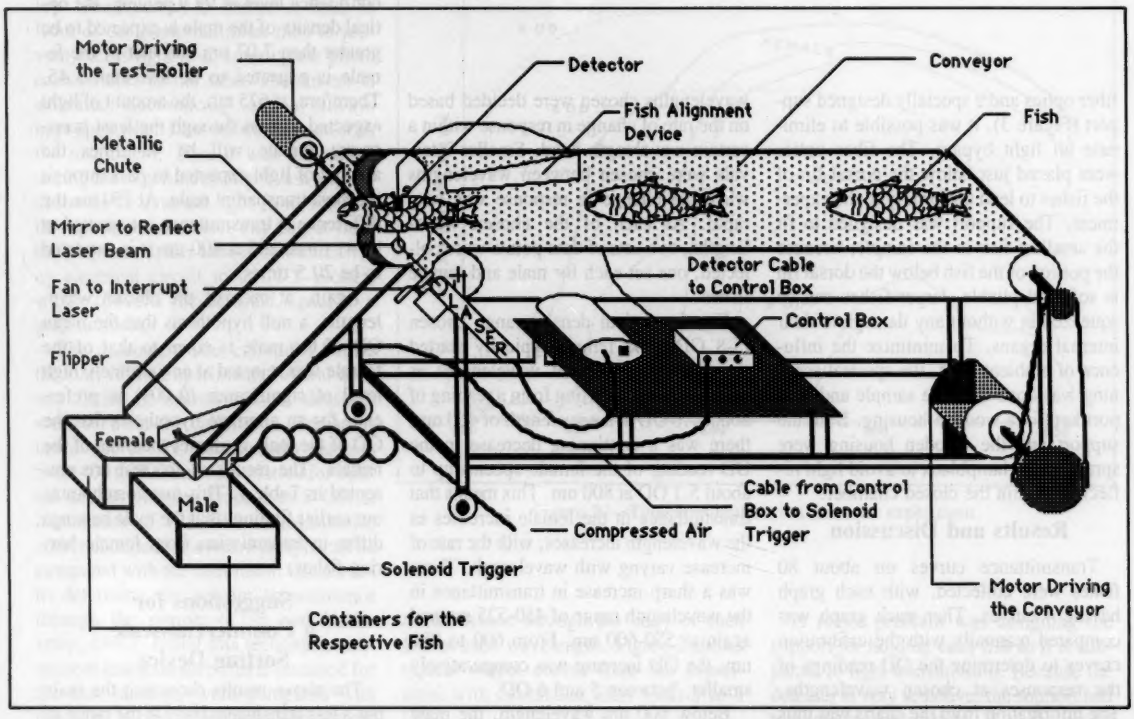

Figure 5.—Schematic representation of a device used for continuous sorting.

Figure 6.—Photograph of a herring sex sorting device using laser technology.

allows less light to pass through its body. For an industrial separation, it would not be feasible to inspect the transmittance response of the fishes throughout the whole range of wavelength as was done in this experiment. Since the male and female fishes had significantly different responses at all wavelengths, one quick test would be to investigate the responses at two prechosen wavelengths. One wavelength could be 525 nm, at which there would be a significant response by the female fish and no response by the male. To confirm the inference obtained from the above response, a second wavelength of 700 nm could be tried. As can be seen from Figure 4, the responses differ greatly at this wavelength. Thus, a definite conclusion can be reached. The test chamber could be linked with a computer which, after interpreting the response, could trigger a mechanical apparatus, that would then channel the tested fish into the appropriate container.

The main difficulty in the development would be the design of the chamber in which the sample has to be housed for the test. Not only would it have to prevent external and other undesirable light from filtering through, it would have to allow quick movement of the sample after it has been tested and subsequent replacement by an untested sample. One way would be to construct a long test chamber so that at its center it has minimum influence of ambient light. The fishes could be transported along a conveyor leading into the test chamber, which would divide into two conveyors at the outlet of the test chamber, one for male and one for female. The fish to be tested can be aligned for testing by moving it in position with a set of parallel vertical rollers. The rollers would maneuver the fish into the support, which has the fiber optics attached to it. The fish would be positioned so that the fiber optics fitted into the support would be below the dorsal fin. The support should be tight fitting for the fish to avoid light bypass. If needed, an adjustable support could be designed that would handle fishes of different sizes. The rollers would stop moving as soon as the fish is aligned in the support, and after the fish was tested they would start moving again and lead the fish back onto a conveyor. Meanwhile, the detected response would activate a mechanical gate, which would channel the fish into the correct conveyor at the outlet. Some of the difficulties with the approach noted in the preceding discussion appear to be the reasons why the Canadian machine did not function well in an industrial environment.

Another design, which would avoid

the construction of a complicated test chamber to keep out ambient light, would involve the use of lasers. A laser beam, being of high-intensity, does not necessarily need a completely covered test chamber. It can be aimed at the sample from a convenient distance and the response can be detected from the other side by a detector properly aligned in a straight line with the incident beam. With fiber optics, one has to clean the ends often, as they get smudged after coming in direct contact with the fishes. This can be avoided with the use of lasers. Relatively inexpensive lasers are available at 600-650 nm wavelength. This means that the tests on the fishes have to be performed in this wavelength range only. However since the response curves show a considerable difference at these wavelengths, there would be no difficulty in arriving at a conclusion about the sex of the fish, and accordingly the fish could be sorted.

A scaled-up version of the laser based system was fabricated in the laboratory as shown in Figure 5. Repeated trials with fish of known sex confirmed the validity of this approach. As seen in Figure 6, the use of lasers does not require extensive shielding of the test area from external light. This will be a preferred design for scaling up for industrial operation.

Conclusions

In the area below the dorsal fin, male and female herrings differ significantly in optical density at 400-800 nm wavelength. A statistical analysis of the results showed that for incident light of the same intensity, transmittance through the bodies of the female is 20-40 times more than that for the male fishes in the range of wavelength used. This shows that there is a good potential for developing a device that would sort fishes by sex on an industrial scale. Using a pair of wavelengths as suggested, and with the use of lasers, this device can be designed.

Acknowledgments

The authors thank Nelson Smith for helping with set up of the apparatus and its use, and especially with the electronic controls associated with the device. The authors also thank S. K. Upadhyaya for valuable suggestions regarding the statistical analysis. Thanks are also due to George Giannini for help in the fabrication of the special support designed to hold the fish.

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Patterns in Longline Fishery Data and Catches of Bigeye Tuna, *Thunnus obesus*

GARY T. SAKAGAWA, ATILIO L. COAN, and NORMAN W. BARTOO

ABSTRACT—Species composition of tunas caught by the large Asian longline fleets has shifted over time. Much of the observed change appears to be market driven, combined with changing economic conditions, as opposed to being driven by resource availability. As part of the strategy for change, the oriental longliners developed the ability to target on certain species with a gear previously thought relatively nonselective with respect to target species. Use of longline catch statistics for resource assessment requires an understanding of the reasons for changes in the data to avoid misuse of the statistics.

Background

Longline gear has been an effective and traditional fishing gear used to catch large tunas in the open oceans. The method was perfected by the Japanese in the 1930's, but its use did not spread outside the Japanese archipelago until after World War II (Shapiro, 1948). Currently, Japan, Korea, and Taiwan have large, specialized fleets that use longlines for catching tunas in the major oceans and seas. As many as 2,000 longline vessels are engaged in fishing primarily for tunas.

The basic design of the longline gear, a long mainline suspended from floats to which branch lines with hooks are attached, is simple and generally uniform between vessels (Shingu et al., 1980). What is unusual is that the gear can be deployed in specialized ways to catch more of certain species than others. This characteristics was most recently shown for the Japanese fleet in the Pacific Ocean. Japanese scientists showed that by removing intermediate floats from a standard longline gear, the mainline sags forming a deeper catenary so that the branch lines fish deeper. Fishermen were able to substantially improve their catch rates for bigeye tuna, *Thunnus obesus*, a preferred species, while reducing the catch rates for other tuna species (Suzuki et al., 1977). Other such techniques, e.g., night longlining for swordfish (Ueyanagi, 1974) have been described in the literature.

In this paper, we review available longline fishery statistics for the Japanese, Korean, and Taiwanese fleets for catch patterns. The patterns are then evaluated with respect to market information, which may have affected tuna fisheries (Suda, 1974; Ueyanagi, 1974; Lee, 1986; Wise and Miyake, 1982). Our emphasis is on the longline catch of bigeye tuna in the Atlantic, but we also review information on the catch of yellowfin tuna, *T. albacares*, and albacore, *T. alalunga*, from other oceans. We do not review, except in a discussion of global events, the catch of bluefin tunas, *T. thynnus* and *T. maccoyi*, because they are caught in specialized fisheries that are monopolized by the Japanese fleet.

The Longline Gear

Longline gear consists of a mainline with float lines and branch lines of baited hooks (Fig. 1). Float lines are attached to the mainline to regulate depth. This gear is deployed for tunas early in the morning and then retrieved, beginning around noon and ending frequently after midnight (Ueyanagi, 1974). Each operation or set involves setting of 150-350 baskets (the mainline is coiled in baskets) of mainline, extending over a distance of 25-75 km, with about 2,000 baited hooks.

Standard longlining fishes at a maximum depth of around 170 m, with 4-6 branch lines per basket of mainline. Deep longlining, which was introduced in the Pacific and Indian Oceans in the early 1970's and in the Atlantic in 1978, fishes at a maximum depth of about 300 m with an average of 13 branch lines per basket (Suzuki et al., 1977). Deep longlining is considered to be more effective than standard longlining for bigeye tuna in certain locations (Suzuki et al., 1977; Suzuki and Kume, 1982).

Longline vessels are categorized as deck-loaded motherships (200-1,000+ gross tons), foreign-based (50-1,000 gross tons) and home-based (30-500 gross tons). Currently, very few vessels greater than 300 gross tons or mothership category are in operation. The larger home-based vessels of 150-500 gross tons are generally modern, have supercold (−40° to −60°C) freezing capability and can remain at sea for up to 3-4 months between fueling stops. These vessels travel to various distant fishing areas, log many months (10-14 months) away from home ports and land their catch directly in Japan. Smaller vessels usually do not have such capability and are based close to the fishing areas. Some vessels rely exclusively on transshipping their catch to consigned markets.

The Markets

Markets for the annual world catch of

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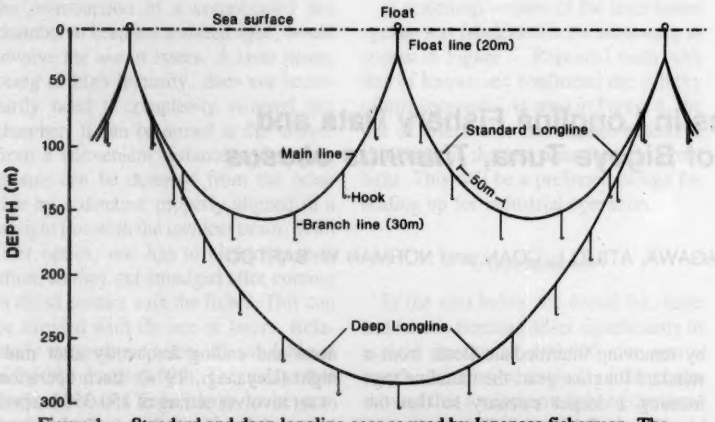


Figure 1.—Standard and deep longline gear as used by Japanese fishermen. The standard gear has an average of 6 branch lines per basket of mainline; deep-longline gear has about 13 branch lines (adapted from Suzuki et al., 1977).

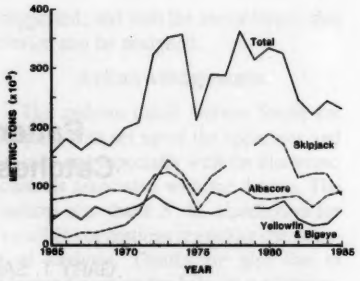


Figure 2.—Tonnage of fresh and frozen tuna by species imported into the United States. Source: Fisheries of the United States, various years.

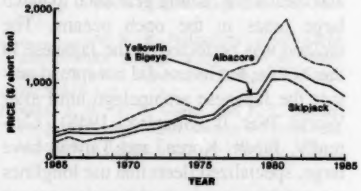


Figure 3.—Average ex-vessel prices paid for tuna delivered to U.S. canneries Source: NMFS, Terminal Island, Calif.

about 400,000 metric tons (t) of longline caught tunas are primarily two: Canned tuna market and "sashimi" market. The canned tuna market has a less stringent fish quality requirement than the sashimi market. Most of the fish for the canned tuna market are caught, refrigerated, and transhipped frozen to cannery facilities. Since the United States is the largest consumer market for canned tuna, consuming in excess of 50 percent of the world's canned tuna production (consumed about 730,000 t in 1984[1]), a significant portion of the longline catch available for canning purposes is sold to U.S. canneries. Thus, U.S. tuna ex-vessel prices and import purchases have a significant effect on the world tuna market.

Data on annual U.S. imports of frozen tuna for the past 20 years (1965-85) show fluctuations in volume (Fig. 2). Much of the fluctuation is due to imports of skipjack tuna, which are not generally caught on longline gear. Imports of the larger tunas (albacore, *Thunnus alalunga*; yellowfin tuna, *T. albacares*; and bigeye tuna, *T. obesus*), which are caught by longliners, show little change in volume over the 20 years, averaging about 75,000 t of albacore and 50,000 t of combined yellowfin and bigeye tuna per year. In other words, over the past 20 years there has not been any significant growth in the demand for longline-caught tunas in the world's largest canned tuna market.

Albacore has traditionally commanded a higher price than yellowfin or bigeye tuna in the U.S. market and is packed exclusively as "white meat" tuna. Yellowfin and bigeye tunas along with skipjack tuna, *Euthynnus pelamis*, are used in "light meat" packs. Prices for these species move in tandem with each other because they are interchangable in the pack.

In the United States, the ex-vessel prices of these "light meat" species showed an upward trend from 1965 to 1981 followed by a downward trend which has continued into 1986 (Fig. 3). The fall in price has been faster for albacore than for yellowfin and bigeye tunas.[1] In 1985, the U.S. prices returned to a level equal to those in 1977 and 1978.

Japan is virtually the sole market for sashimi, or tuna consumed raw. This market is sensitive to both supply and quality (particularly freshness, color, firmness, and fat content) and generally deals with large tunas. About 340,000-360,000 t of both fresh and super-cold frozen tuna are sold annually by the sashimi market. This market has not shown significant growth since the 1960's[2].

About 75 percent of the market is super-cold frozen tuna landed primarily by longliners. Japanese longliners supply most of the tuna, although recently Taiwanese and particularly Korean longliners have exported a significant amount of tuna to this market. Korean and Taiwanese vessels are supplying this market with about 90,000-120,000 t annually[2] and land most of their catch directly in Japanese ports (Uyemae, 1975).

Prices for sashimi-quality tuna in Japan are quite variable. In general, highest prices are paid for bluefin tuna, *T. thynnus* (southern and northern) followed by bigeye tuna, yellowfin tuna,

[1]Herrick, S. F., Jr., and S. J. Koplin. 1985. U.S. tuna trade summary, 1984. Natl. Mar. Fish. Serv., SWR Admin. Rep. SWR-85-06, 24 p.

[2]Fujinami, N. 1986. Option for distant water countries. Manuscr. pres. at Tuna Workshop on Options for Cooperation in the Development and Management of Global Tuna Fisheries, 29 June-3 July 1986, Vancouver, B.C., 16 p.

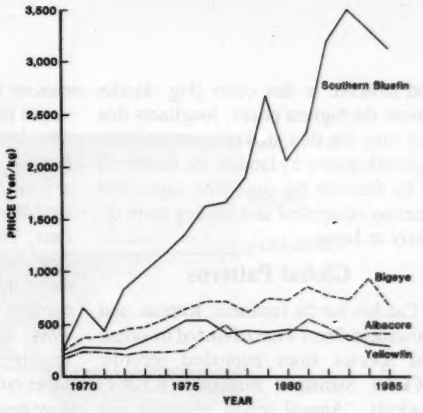


Figure 4.—Average wholesale price of sashimi-grade tuna sold at the Yaizu fish market in Japan. Source: Shingu et al., 1980.

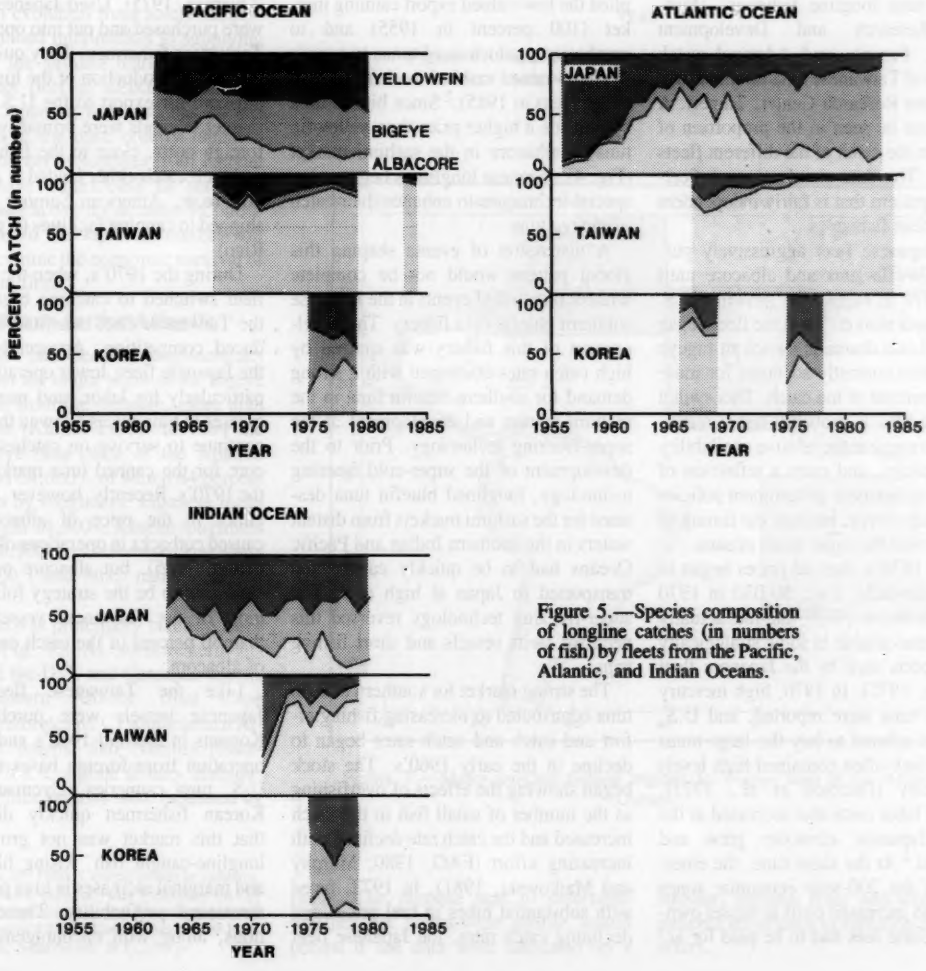


Figure 5.—Species composition of longline catches (in numbers of fish) by fleets from the Pacific, Atlantic, and Indian Oceans.

and albacore in that order (Fig. 4). To ensure the highest prices, longliners that fish tuna for this market must maintain high fish quality by landing the tuna fresh or by freezing the tuna with super-cold freezing equipment and landing them directly in Japan.

Global Patterns

Catches for the Japanese, Korean, and Taiwanese fleets were tabulated by ocean and species from published records: "ICCAT Statistical Bulletin" (ICCAT, Madrid), "Annual report of effort and catch statistics by area on Japanese longline fishery" (Fisheries Agency of Japan, Tokyo), "Annual report of catch and effort statistics and fishing grounds on Korean tuna longline fisheries" (Fisheries Research and Development Agency, Pusan), and "Annual catch statistics of Taiwanese tuna longline fishery" (Tuna Research Center, Taipei). A pattern can be seen in the proportion of species in the catch of the different fleets (Fig. 5). The data clearly show a fleet-specific pattern that is fairly independent of the ocean fished.

The Japanese fleet aggressively pursued yellowfin tuna and albacore until about 1970 to supply the growing U.S. canned tuna market. Then the fleet began a gradual and dramatic switch to bigeye tuna, which currently accounts for more than 50 percent of the catch. This switch to bigeye tuna is probably less a reflection of changes in the relative availability of the species, and more a reflection of changes in Japanese government policies and market forces, because the timing of the shift was the same in all oceans.

In the 1970's, fuel oil prices began to rise substantially, e.g., \$0.03/l in 1970 versus \$0.06/l in 1973[2], and fuel actually became unavailable in some strategically located ports used by the Japanese fleet (Uyemae, 1975). In 1970, high mercury levels in tuna were reported, and U.S. canneries refused to buy the large tunas because they often contained high levels of mercury (Peterson et al., 1973). Japanese labor costs also increased as the overall Japanese economy grew and prospered.[2] At the same time, the emergence of the 200-mile economic zones resulted in increased costs to vessel owners as license fees had to be paid for access to some choice fishing areas. Ex-vessel prices of tuna for canning, on the other hand, were rising only about half as fast as costs (Fig. 3). This resulted in several bankruptcies and threatened the long-term survival of the entire Japanese fleet. The strategy adopted by Japan to cope with these economic forces was threefold: 1) a 21 percent reduction in the number of vessels between 1975 and 1984, while retaining the more efficient vessels[2]; 2) greater utilization of the super-cold freezing technology to produce quality fish for the sashimi market; and 3) the value of each load of tuna was enhanced through emphasis on higher valued species. In other words, the strategy was to reduce production that supplied the low-valued export canning market (100 percent in 1955) and to emphasize production of tunas to supply the high-valued sashimi market of Japan (80 percent in 1985).[2] Since bigeye tuna commands a higher price than yellowfin tuna or albacore in the sashimi market (Fig. 4), Japanese longliners began using special techniques to enhance their catch of bigeye tuna.

A discussion of events shaping this global pattern would not be complete without mention of events in the Japanese southern bluefin tuna fishery. The development of this fishery was spurred by high catch rates combined with a strong demand for southern bluefin tuna in the sashimi market and development of the super-freezing technology. Prior to the development of the super-cold freezing technology, longlined bluefin tuna destined for the sashimi markets from distant waters in the southern Indian and Pacific Oceans had to be quickly caught and transported to Japan at high cost. The super-freezing technology reversed this need for swift vessels and short fishing trips.

The strong market for southern bluefin tuna contributed to increasing fishing effort and catch and catch rates began to decline in the early 1960's. The stock began showing the effects of overfishing as the number of small fish in the catch increased and the catch rate declined with increasing effort (FAO, 1980; Murphy and Majkowski, 1981). In 1972, faced with substantial hikes in fuel prices and declining catch rates, the Japanese fleet was in financial trouble. The fleet adopted voluntary measures to stabilize fishing effort in this fishery (ICCAT, 1986). Despite this, catch and catch rates continued to fall. We suspect that difficulties in this major Japanese longline fishery precipitated the adoption of a new strategy. The new strategy allowed the Japanese to shift excess capacity out of the southern bluefin tuna fishery into an underdeveloped bigeye tuna fishery to supply the domestic market, while retaining its modern, specialized longliners with super-cold freezing capacity.

Taiwan entered the longline industry during a period when the Japanese fleet was undergoing modernization and expansion in the late 1950's to early 1960's (Uyemae, 1975). Used Japanese vessels were purchased and put into operation by Taiwanese fishermen. They quickly specialized in production of the high-valued albacore for export to the U.S. canning market. Vessels were primarily based in foreign ports, close to the fishing areas and their catch either landed at a cannery port (e.g., American Samoa) or transshipped to canning facilities (e.g., Puerto Rico).

During the 1970's, when the Japanese fleet switched to catching bigeye tuna, the Taiwanese fleet benefited by the reduced competition. Apparently, unlike the Japanese fleet, lower operating costs, particularly for labor, and marginal increases in tuna prices allowed this fleet to continue to survive on catches of albacore for the canned tuna market during the 1970's. Recently, however, sharp declines in the price of albacore have caused cutbacks in operations of this fleet (Yang, 1985), but albacore production continues to be the strategy followed by most of the Taiwanese vessels. More than 80 percent of the catch currently is of albacore.

Like the Taiwanese fleet, used Japanese vessels were purchased by Koreans in the mid-1960's and put into operation from foreign bases to supply U.S. tuna canneries (Uyemae, 1975). Korean fishermen quickly discovered that this market was not growing for longline-caught fish. Rising fuel prices and marginal increases in tuna prices also threatened profitability. These realizations, along with encouragement from

Japanese trading companies, caused some vessels to switch fishing for the canned tuna market and to concentrate on the higher value sashimi market. The Koreans were successful in adapting technology for fishing bigeye tuna and in using import privileges that allowed direct landings in Japan. By 1974, direct landings by Korean longliners in Japan were 40,000 t of primarily sashimi-grade tuna (Uyemae, 1975). Further advances included adopting supercold freezing capability and acquiring larger vessels resulted in the current catch pattern for the Korean fleet being nearly identical to that of the Japanese fleet (Fig. 6). By 1982, Korean vessels landings in Japan grew to 56,000 t. The net effect for the Korean fleet is an evolution from solely supplying the canned tuna market to supplying primarily the sashimi market. This has placed this fleet in direct competition with the Japanese fleet and has caused disruption of the once orderly Japanese sashimi market as supplies from Korean vessels have contributed to surpluses substantially above the demand[3]. Continued access to the Japanese market will likely determine the economic survival of the Korean fleet.

Patterns in the Atlantic

Over the past decade, longliners accounted for the major share of the bigeye tuna catch from the Atlantic, more than 62 percent (Kume, 1985). In 1984 the total bigeye tuna catch of the Atlantic Ocean was 64,600 t, of which 64 percent was taken by longliners. Japanese longliners caught 24,300 t, Korean longliners caught 10,900 t, Taiwanese longliners caught 800 t and other nations the remainder.

The catch is principally taken in three regions (Fig. 7): A) northwestern Atlantic, off the U.S. and Canadian coasts; B) northeastern Atlantic from Cape Verde to Azores; and C) southeastern Atlantic off Angola and Nambia (Sakagawa, 1976). Longline fishery statistics for these three regions were tabulated by fleets. The purpose was to determine whether the ocean-wide profile would persist if the data were tabulated on a smaller, regional scale and whether the patterns are related to variation in fishing effort.

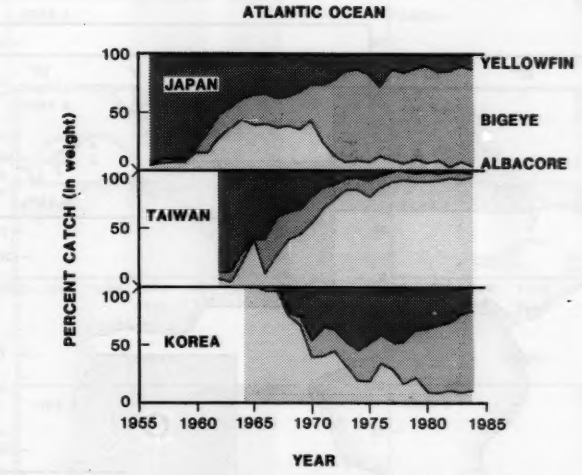


Figure 6.—Species composition of longline catches (in weight) from the Atlantic Ocean.

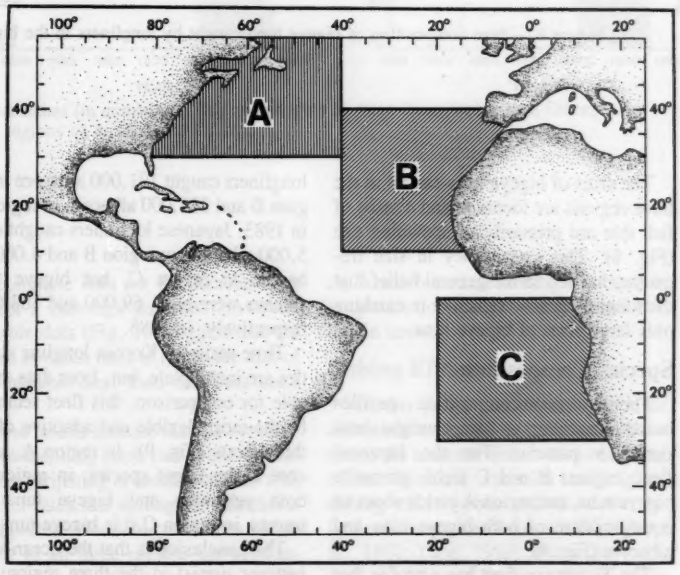


Figure 7.—Major longline fishing regions for bigeye tuna in the Atlantic Ocean.

[3]Yamashita, H. 1986. Current trends in industry, Japan. Manuscr. pres. at Tuna Workshop on Options for Cooperation in the Development and Management of Global Tuna Fisheries, 29 June-3 July 1986, Vancouver, B.C., 16 p.

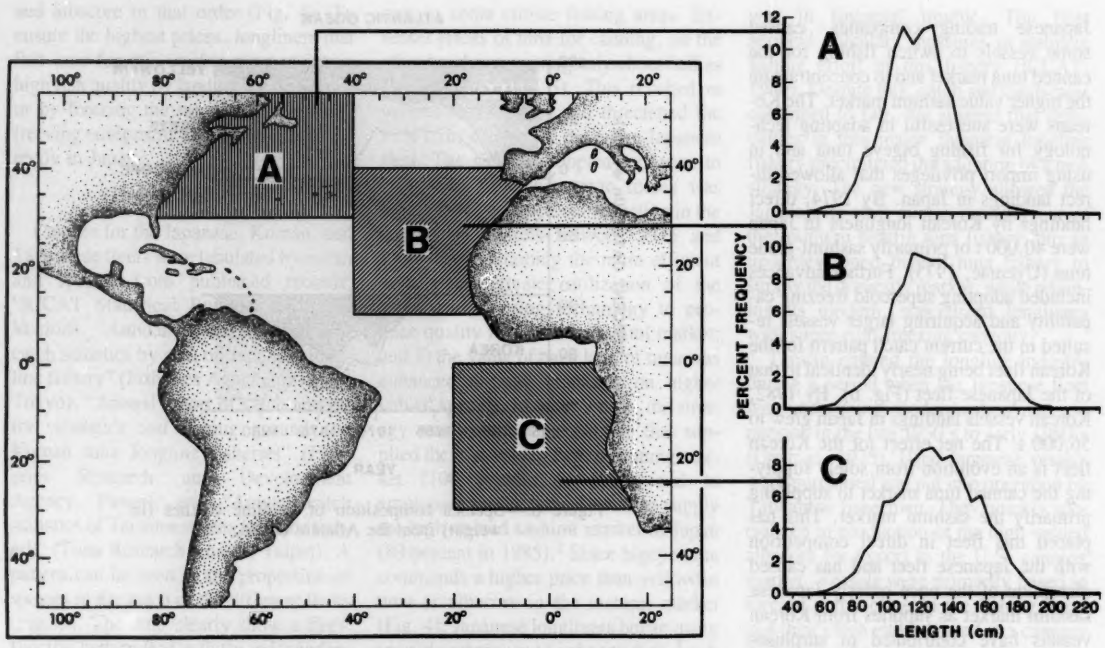


Figure 8.—Size composition of bigeye tuna caught by longliners in the bigeye tuna fishing regions of the Atlantic.

The sizes of bigeye tuna caught in the three regions are identical and consist of fish that are primarily of spawning age (Fig. 8). This consistency in size frequency has led to the general belief that the longline gear is selective in catching only large sizes of bigeye tuna.

Species Composition

The species composition profiles based on numbers of fish or weight show particular patterns. For the Japanese fleet, regions B and C yield primarily bigeye tuna, but region A yields about an equal mixture of both bigeye tuna and albacore (Fig. 9).

The Taiwanese fleet has a profile that is consistent for all three regions when viewed by numbers or weight, i.e., predominantly albacore (Fig. 9). In regions B and C, which Japanese data indicate are bigeye tuna fishing areas, less than 10 percent of the Taiwanese catch is bigeye tuna and more than 80 percent is albacore. In terms of numbers, Taiwanese longliners caught 191,000 albacore in region B and 203,000 albacore in region C in 1983. Japanese longliners caught only 5,000 albacore in region B and 4,000 albacore in region C, but bigeye tuna catches were high, 69,000 and 188,000, respectively, in 1983.

Time series of Korean longline statistics are incomplete, but, from data available for comparison, this fleet seems to be the most flexible and adaptive of the three fleets (Fig. 9). In region A, albacore is the target species; in region B, both yellowfin and bigeye tuna are targets; in region C it is bigeye tuna.

The conclusion is that the ocean-wide patterns persist in the three regions for the Taiwanese fleet, two regions for the Japanese fleet, and one region for the Korean fleet. Thus, regional fishing areas and fleet operations both determine what species are caught and their ratio in the catch.

Catch Rates

It might be argued that patterns in species composition of the catch are due to a normal evolution of a multispecies fishery in which declining catch rate for one species results in switching to another species with a higher catch rate. We examined this hypothesis using nominal catch rates by fleets and regions.

The catch rates for the Japanese fleet vary within a region, but there is a clear pattern (Fig. 10). The high catch rates for albacore (average of 30 fish/1,000 hooks in regions A and C) were followed by sharp declines in the early 1970's when switching to bigeye tuna occurred. This was followed by a leveling off of the albacore catch rate at a low level. The catch rate for bigeye tuna in comparison shows less variation. Since 1970 it has fluctuated between 5 fish/1,000 hooks and 20 fish/1,000 hooks, and since 1974 it has surpassed the albacore rate in nearly all years. The effect of deep longlining, i.e.,

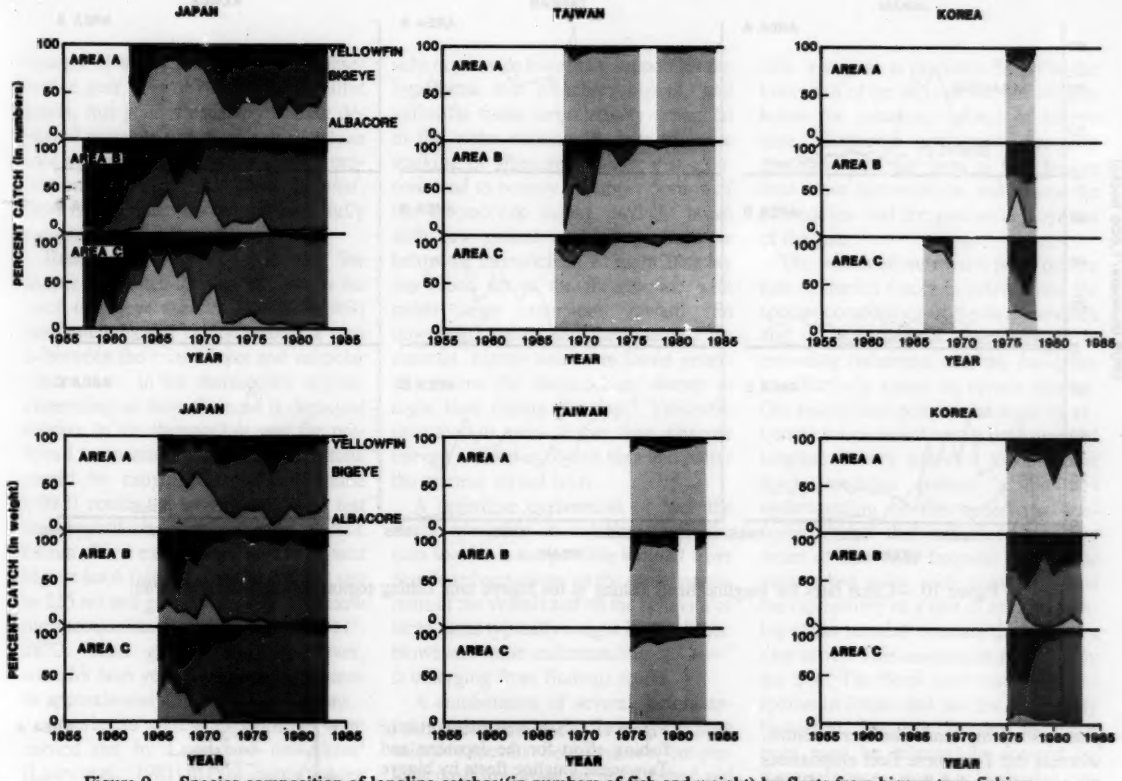


Figure 9.—Species composition of longline catches (in numbers of fish and weight) by fleets from bigeye tuna fishing regions of the Atlantic Ocean.

superior catch rate for bigeye tuna, since 1978 is not evident in the data possibly due to limited amounts of effort by this gear; so, we conclude that its effect, if any, is negligible.

In comparison, the Taiwanese fleet shows catch rates of albacore that are high although variable (Fig. 10). The catch rates are comparable to rates that the Japanese fleet was experiencing before the switch to bigeye tuna occurred in the early 1970's and are substantially higher than catch rates for bigeye tuna. The reduced competition by Japanese longliners for albacore in region B appears to have contributed to improved catch rates for Taiwan longliners operating in that region. The Taiwanese fleet appears to have selected the species with the highest catch rate.

Incomplete data for the Korean fleet prevent a thorough analysis. However, available data (Fig. 10) suggest that the pattern of catch rates is more like that of the Japanese fleet than the Taiwanese fleet.

These results indicate that the hypothesis that declining catch rate of one species triggers switching to another species with a higher catch rate in longline fisheries is unsupported. Nominal catch rates for albacore in all three regions are substantially higher than for bigeye tuna or yellowfin tuna, yet only the Taiwanese fleet concentrates on fishing for albacore. The Japanese fleet abandoned the high catch rates for albacore in 1970-71 to concentrate on bigeye tuna with a lower catch rate. Similarly, the Korean fleet is not pursuing the species with the highest catch rate, but concentrating on a mixture of species dominated by bigeye and yellowfin tunas.

Fishing Effort

Another factor that might explain the difference in patterns in species composition is the seasonal distribution of fishing effort. Seasonal variation in longline fishing effort within regions of the Atlantic Ocean is well known (Shingu et al., 1980; Yang, 1980). But is the variation so different between the Japanese and Taiwanese fleets to cause one fleet to catch a significantly higher proportion of bigeye tuna while the other does not?

The seasonal pattern of fishing effort by fleet for 1983 (Fig. 11) indicates that in region A, both fleets have similar patterns. In region B, the Japanese fleet con-

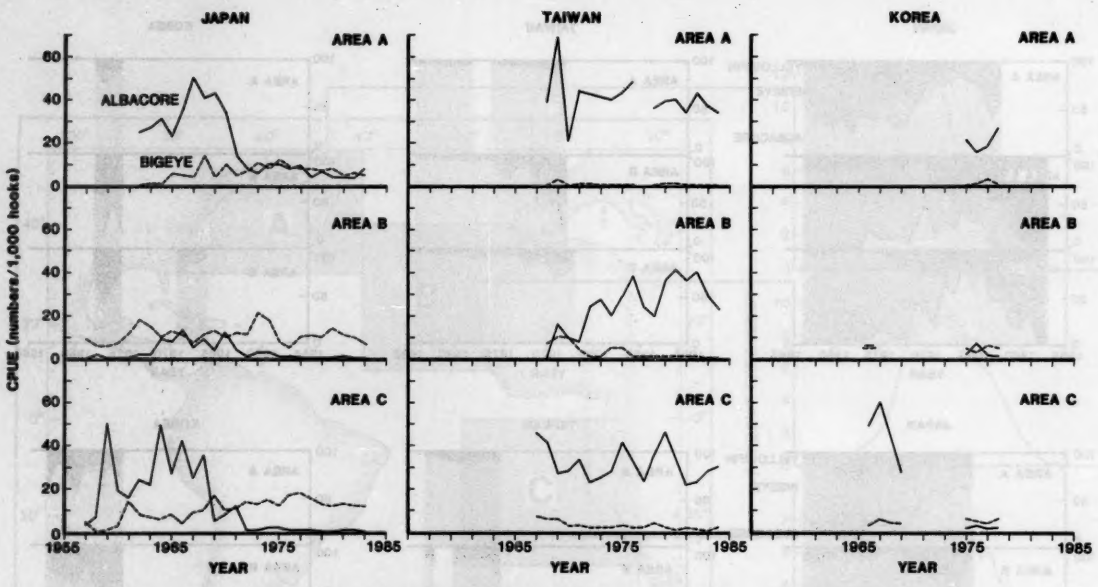


Figure 10.—Catch rates for longline fleets fishing in the bigeye tuna fishing regions of the Atlantic Ocean.

phasizes spring and summer months, whereas the Taiwanese fleet emphasizes the summer and fall. In region C, the difference is in the spring and summer months when the Japanese fleet is not operating, whereas the Taiwanese fleet is active.

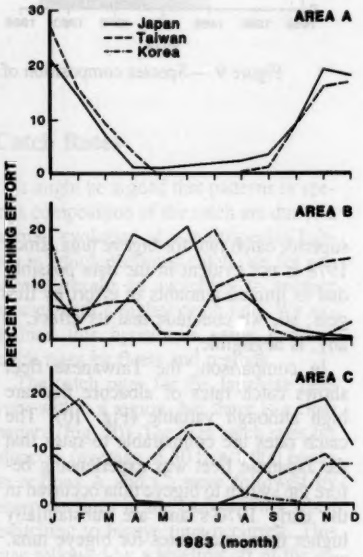
Within regions B and C, besides differences in seasons fished, fishing effort for the Japanese fleet tends to be concentrated towards the equator, whereas the Taiwanese fleet concentrates in areas toward the poles. Thus, in regions B and C, seasonal differences in fishing effort are a factor causing more of one species to be caught than another. However, this is obviously not the sole factor, since in region A the two fleets fishing similar locations and seasons but caught different proportions of tuna species.

Basis for Patterns

Longlining is considered a labor-intensive form of fishing with catch rates relatively low compared with other forms of tuna fishing. Fuel and labor constitute 75 percent of the expenses of operating a longline vessel (Uyemae, 1975). It is estimated that a 300 gross ton Japanese vessel spends about $500,000 for expenses on a 10-month fishing trip which, on the average, results in a full load (Uyemae, 1975). Obviously, even at the highest historical prices offered by U.S. canneries (Fig. 3), a longliner can barely break even, whereas with prices for sashimi-grade bigeye tuna (about $2,300/t) a profit is possible. Market forces thus have played a major role in influencing the fleets to specialize and concentrate on certain species.

These market forces through time have influenced the operations of the longline fleets and have shaped their strategy so that each specializes in certain species for particular markets. This is remarkable, given that the longline gear is often

Figure 11.—Seasonal distribution of fishing effort for the Japanese and Taiwanese longline fleets by bigeye tuna fishing regions of the Atlantic Ocean.



thought of as an indiscriminate, nonselective gear. It is obvious that in skillful hands, this gear is capable of being deployed to catch a particular mix of tuna species with significantly different proportions of one species over another. How this is done has not yet been fully explained.

Hanamoto (1976) contends that the deeper the branch lines are the greater the catch of bigeye tuna. Suda et al. (1969) postulated that the habitat of bigeye tuna is between the mixed layer and subpolar waters, i.e., in the thermocline region. Depending on how the gear is deployed relative to the thermocline and the preferred temperature of 20°C bigeye tuna would be caught. Suzuki and Kume (1982) conducted an experiment to test this hypothesis in the western Pacific Ocean. Their experiment yielded highest bigeye hook rates for the deepest sets (up to 225 m) and good catches in and below the thermocline in temperatures of 11°-26°C. Their good catches, however, were for both yellowfin and bigeye tunas in approximately the same proportions.

A series of similar experiments were carried out by Laurs and coworkers[4] (Laurs et al., 1981) in exploratory fishing for albacore in the eastern north Pacific Ocean. They used vertical and horizontal temperature profiles to select fishing areas and to position their longline gear. They concluded that thermal fronts with temperatures of 16°-19°C tend to concentrate albacore. Good catches of albacore were obtained while fishing in the top half of the thermocline where the 16°C isotherm was located. Their experiment produced catches of both albacore and bigeye tuna, but albacore made up more than 90 percent of the catch.

Tracking experiments of tunas tagged with ultrasonic transmitters have been conducted to study the vertical and horizontal movements of tunas. While experiments so far have used tunas smaller than those of average size in longline catches, which may make the results somewhat atypical for larger fish, the results do provide biological support for the hypothesis that albacore, bigeye, and yellowfin tunas are relatively separated in the water column. Results of sonic tracking of albacore[4,5], show that albacore tend to occupy the upper portion of the thermocline during daylight hours with few radical excursions above or below the thermocline. At night albacore are found above the thermocline with rather large excursions upward and downward below the thermocline. By contrast, bigeye tuna were found generally below the thermocline, deeper at night than during the day.[6] Yellowfin tuna tend to swim deeper than albacore but not as deep as bigeye tuna and prefer the warmer mixed layer.

A definitive explanation of how the fleets specialize in catching particular tuna species is not possible without more detailed observations on the actual operations of the vessels and on the behavior of large tunas typically caught by the fleets. However, some understanding of "how" is emerging from findings so far.

A combination of several factors appears to be used by the fleets in catching selective species. Season is one, but perhaps most important are areas fished and gear deployment. Fishing for albacore is concentrated in temperate regions where albacore is the dominant species and where they occur frequently along thermal fronts created by polar waters meeting warmer waters. The 16°C isotherm is used as an indicator of preferred water. Vertically, fishing in the thermocline or just above it in 16°-19°C waters assures catches to be predominantly albacore.

Fishing in the tropical and subtropical regions results in primarily bigeye and yellowfin tuna catches. Yellowfin tuna occupies primarily the mixed layer but extends into the thermocline. Bigeye tunas are found deeper, within the thermocline and below in 11°-26°C water. Gear deployment in these regions requires more skill for targeting on one species. The gear is probably fished in the lower half of the thermocline and slightly below for enhanced catches of bigeye tuna. Electronic equipment, probably chromoscopes, are used to find bigeye tuna more accurately in and below the thermocline and for precise deployment of the gear.[7]

The results of our review point out the role of market forces in determining the species composition of the longline catch and of technological developments in providing fishermen with the capability to effectively target on certain species. Our results also point to the need for extreme caution in utilizing a time series of longline fishery statistics to determine stock condition without a thorough understanding of the underlying economic events that influenced the time series of data. The frequent assumption made when using such statistics is that the catchability of a unit of longline fishing effort remains constant throughout a time series. This assumption is obviously not true. The fleets have evolved in response to forces that are not completely biological. The data on catch and catch rates must be adjusted to account for these responses, and it is likely that current practices do not fully accomplish this.

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Table for Estimating Histamine Formation in Skipjack Tuna, *Katsuwonus pelamis*, at Low Nonfreezing Temperatures

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ABSTRACT—Histamine levels were measured in fresh, whole skipjack tuna, Katsuwonus pelamis, *that had been incubated at 30°, 40°, and 50°F, and an equation was derived from the data to describe the relationship between histamine formation and incubation time at low nonfreezing temperatures. Values obtained with this equation were used to make a table showing how long it would take for the development of specific histamine levels at several temperatures ranging from 30° to 60°F. The table could be used to estimate decomposition during cold storage of skipjack tuna before the fish are frozen on commercial fishing vessels.*

Introduction

Histamine is not present in the muscle tissue of fresh fish but can be found in some marine fish that have decomposed or have been involved in food poisoning incidents (Kimata, 1961; Arnold and Brown, 1978; Omura et al., 1978; Frank et al., 1981; Behling and Taylor, 1982; Yoshinaga and Frank, 1982; Frank et al., 1983; Frank, 1985a, b; Frank et al., 1985; Taylor, 1986). Histamine is produced through bacterial decarboxylation of the free histidine present in scombroid fish (Kimata, 1961; Arnold and Brown, 1978; Omura et al., 1978; Arnold et al., 1980; Yoshinaga and Frank, 1982; Frank and Yoshinaga, 1984; Frank, 1985a; Taylor, 1986) and other species (Taylor, 1986), including the dolphin or mahimahi, *Coryphaena hippurus*, (Frank et al., 1985).

For many years the tuna canning industry used honeycomb formation as a simple, rapid criterion for determining whether decomposition is present (Frank et al., 1984). However, during the past several decades the industry, as well as various agencies, have employed histamine as a quantitative indicator of the loss in quality through bacterial spoilage (Frank et al., 1981, 1983, 1985). Other microbial end products have also been suggested as indicators of decomposition in tuna, including volatile acids, trimethylamine, hypoxanthine, volatile reducing substances, ethanol, and particularly putrescine and cadaverine (Mietz and Karmas, 1977; Ritchie and Mackie, 1980; Frank et al., 1981; Staruszkiewicz and Bond, 1981; Frank et al., 1985), but to date none has been used as widely as histamine to measure deterioration in quality. In 1982 the U.S. Food and Drug Administration (FDA) established histamine levels above 50 mg per 100 g canned tuna as a potential health hazard and 20 mg as an indication of substantial prior decomposition (Food and Drug Administration, 1982). These levels have been used as the basis for FDA regulatory actions.

Numerous histidine decarboxylating bacteria have been isolated from decomposed and fresh scombroid fish and mahimahi, but these have been mainly mesophilic members of Enterobacteriaceae and others belonging to *Vibrio*, *Lactobacillus*, and *Clostridium perfringens* (Arnold and Brown, 1978; Omura et al, 1978; Behling and Taylor, 1982; Yoshinaga and Frank, 1982; Frank et al., 1985; Frank, 1985a; Taylor, 1986). However, only a few studies are available on histamine production at low temperatures in fish or in cultures of psychrotrophic bacteria. Histamine formation in fish has been observed in the range of 32°-50°F, but results have varied. Behling and Taylor (1982) reported that *Klebsiella pneumoniae* produced histamine slowly at 44.6°F in a medium containing histidine. Frank and Yoshinaga (1984) observed histidine decarboxylation at 39°F by whole cell suspensions of *K. pneumoniae* that had been grown at 100°F. Okuzumi et al. (1981) isolated a group of unidentified halophilic, psychrophilic, histamine-forming bacteria (called N-group bacteria) from mackerel homogenates at 41°F. N-group bacteria are regarded as part of the normal microflora of marine fish (Okuzumi et al., 1982) and have been isolated from several fresh histidine-containing fish (Okuzumi et al., 1984). Frank et al. (1985) reported that decarboxylation of histidine, ornithine, and lysine was comparable among cultures of mesophilic and psychrotrophic bacteria isolated from mahimahi. Nonetheless, they concluded that cadaverine and putrescine might be less suitable as indices of decomposition because of the low substrate levels of lysine and ornithine in mahimahi. Baranowski (1985), who reported slight urocanic acid production from histidine at 50°F by 58 of 166 psychrotrophic bacteria isolated from mahimahi, suggested that urocanic acid might be an alternative to histamine as a quality index at low temperatures.

On commercial purse seiners, the fish are brought on board the vessel, cooled in a well containing refrigerated seawater

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(RSW) at 28°-30°F, frozen in a brine and stored at 15°-20°F in dry wells until the boat is unloaded at the cannery. Depending on how quickly the fish are cooled, the process may provide opportunities for microbial growth, especially by psychrotrophic bacteria. Individual large fish cool slowly, and a large load of fish placed simultaneously in the hold also cools slowly, particularly at the geometric center. Thus, the fish in a well may take several days to reach the temperature of the RSW (30°F). Also, freezing may be delayed when there are not enough fish to fill the hold, and the fish are kept unfrozen for periods ranging from a few days to 3 weeks until more are added (Behling and Taylor, 1982). The end result is that psychrotrophic bacteria could cause spoilage that may be accompanied by histamine formation. Needless to say, fish on boats that employ icing only to lower the fish temperature would be particularly vulnerable to spoilage by psychrotrophic bacteria.

Earlier we prepared a nomograph for estimating histamine production in skipjack tuna at warm temperatures (Frank et al., 1983) based on a study of controlled decomposition in incubated fresh fish. However, the original equation for the nomograph inferred that bacterial histamine production ceased at 32°F, whereas Ratkowsky et al. (1982, 1983) have shown that the rate of bacterial growth is dependent on the difference between the ambient temperature and T_o, a hypothetical temperature that is intrinsic to the organism. Consequently, the equation for the nomograph was modified to include this concept, and a revised nomograph was prepared accordingly (Frank, 1985b).

This paper includes a table for estimating histamine formation at low nonfreezing temperatures (30°-60°F), also based on an equation derived from a study of controlled decomposition in incubated fresh skipjack tuna, and including the T_o concept. This table could be used in the fishing industry to determine the extent of spoilage during the handling of tuna at low nonfreezing temperatures.

Table 1.—Histamine formation in skipjack tuna at low temperatures[1].

Temperature and time (days)	Histamine (mg/100 g tuna)		
	Trial 1	Trial 2	Mean
30°F			
0			0.11[2]
7	0.16	0.28	0.22
14	0.30	0.45	0.38
21	0.09	0.29	0.24
28	0.13	0.14	0.14
35	0.20	0.44	0.32
42	1.93	3.09	2.01
40°F			
0			0.11[2]
4	0.58	0.71	0.65
8	0.51	0.60	0.56
14	1.83	9.85	5.84
20	16.4	17.7	17.1
24	7.12	7.46	7.29
50°F			
0			0.11[2]
3	0.31	0.47	0.39
6	0.53	0.56	0.55
9	2.86	4.72	3.79
12	11.5	22.3	16.9

[1]Fresh, whole fish were placed in separate polyethylene bags containing seawater, incubated at the times and temperatures shown, and analyzed for histamine.
[2]Six fish. All other values were obtained from duplicate fish incubated at times and temperatures indicated.

Materials and Methods

Fish

Live skipjack tuna, weighing about 4-5 pounds (1.8-2.3 kg) each, were obtained locally and handled as described previously (Frank et al., 1981) to assure freshness of the fish.

Incubation

Individual fish were placed in separate polyethylene bags containing 4-5 liters of filtered fresh seawater and incubated for the desired times at 30°, 40°, or 50°F as described by Frank et al. (1981). Each incubation was run in duplicate.

Histamine

The histamine content in each fish was measured by the AOAC fluorometric method as described by Frank et al. (1983). The mean of the composite histamine levels for both sides was used as the histamine level of each fish.

Results and Discussion

Equation for Histamine Formation at Low Temperatures

Table 1 shows the effect of incubation time on histamine formation in skipjack tuna over the range of 30°-50°F, a relationship that can be expressed mathematically by the power function equation

$$H = a \cdot t^x \cdot F^y, \qquad (1)$$

where

H = histamine (mg/100 g tuna),
t = time in days,
F = incubation temperature (°F), and
a, x, and y = constants.

Previously (Frank, 1985b), the power function equation for mesophilic spoilage of skipjack tuna was adapted to include T_o, a hypothetical temperature that is the theoretical minimum for the process under consideration but is not the minimum growth temperature (McMeekin and Olley, 1986). In this paper, Equation (1) was adapted to include T_o for psychrotrophic spoilage, and a modified equation was obtained in which

$$H = a \cdot t^c \cdot (F - F_o)^b, \qquad (2)$$

where

$F_o = T_o$ (Ratkowsky et al., 1982, 1983), °F, and
a, b, c = constants.

The data in Table 1 were fitted by the method of least squares (Draper and Smith, 1966), and Equation (2) was converted to the following equation which accounted for 49.4 percent of the variance:

$$H = 1.927 \cdot 10^{-7} \cdot (F - F_o)^{4.436} \cdot e^{(0.086857)t}, \qquad (3)$$

or

$$H = 1.927 \cdot 10^{-7} \cdot (F - 12.92)^{4.436} \cdot (1.0907)^{t} \quad (3a)$$

where

$e = 2.71828$ (base of natural logarithms), and

$F_o = 12.92°F$ (calculated from the "square root" equation of Ratkowsky et al. (1982, 1983) after plotting log H vs. log t and setting 2.5 mg histamine per 100 g tuna as the spoilage level); this value is typical of those reported for other types of psychrotrophic spoilage (Ratkowsky et al., 1982).

Equation (3a) was used to calculate the incubation periods needed for accumulation of different levels of histamine in skipjack tuna at temperatures in the range of 30°-60°F, as shown in Table 2.

Table 2.—Effect of incubation time and temperature on histamine formation in skipjack tuna.

Histamine, mg/100 g tuna	Days required to produce indicated histamine level[1] at various temperatures						
	30°F	35°F	40°F	45°F	50°F	55°F	60°F
0.5	25	12	2	< 1			
1.0	33	20	10	1			
2.5	40	27	17	8	1		
5	52	38	28	19	12	6	
10	60	46	36	27	20	14	8
20	65	51	41	32	25	19	13
50	78	64	55	45	38	32	26
100	86	73	63	54	46	40	34
500	104	91	81	72	65	58	52

[1]Calculated from text Equation (3a):

$H = 1.927 \cdot 10^{-7} \cdot (F - 12.92)^{4.436} \cdot (1.0907)^{t}$,

where H = histamine (mg/100 g tuna), F = temperature (°F), and t = incubation time in days.

Use of Table 2

The effect of lowering the fish temperature on the rate of psychrotrophic microbial spoilage is illustrated in Table 2. For example, production of 1 mg histamine per 100 g tuna would take only 1 day at 45°F, a typical food refrigerator temperature, but would take 33 days at 30°F.

Obviously, histamine formation would be negligible when the hold of the fishing vessel is filled rapidly and the fish are frozen immediately after being caught. However, when the volume of fish is too small to fill the hold, the fish may be kept unfrozen for as long as 3 weeks (Behling and Taylor, 1982), and a decision would be needed eventually on when to freeze the catch to prevent additional deterioration. The ability to estimate histamine production through knowing the fish temperature and incubation time would be useful in dealing with the problems stemming from long-term storage at low temperatures. Thermocouples can be used to measure the fish temperature during storage and the histamine level for a given time period can be determined from Table 2. Intermediate values that do not appear in Table 2 can be calculated by interpolation.

Temperature Function Integrators

Temperature function integration is based on the cardinal role of temperature in affecting microbial growth and the rate of food spoilage. Temperature function integrators (McMeekin and Olley, 1986) are commercially available electronic devices that can continuously accumulate measurements of the changing temperatures in a product during storage. When the relationship is known between incubation conditions (time and temperature) and the spoilage rate in a food, the circuitry of these instruments can be calibrated to integrate the measurements into an expression that represents the total deterioration in that product. Since this expression also can be stated as an equivalent storage time at some reference temperature, the shelf life remaining in the food can be predicted for any known combination of time and temperature.

Temperature function integrators can be adapted for estimating spoilage in fish (Olley and McMeekin, 1985). The mathematical model reported previously for mesophilic histamine formation in skipjack tuna (Frank, 1985b) could be employed in estimating spoilage at moderate temperatures when fish are being cooled slowly, e.g., at the center of a hold that has been filled rapidly. Likewise, the model described above for psychrotrophic histamine formation could be used to monitor spoilage during prolonged holding at low nonfreezing temperatures on fishing vessels. However, application of these models to histamine formation in other histidine-containing fish should be done with caution. Because various species of marine fish have different histidine levels (Lukton and Olcott, 1958; Hibiki and Simidu, 1959; Suyama and Yoshizawa, 1973) as well as dissimilar microfloras, the rates and levels of histamine formation can be expected to differ from those observed in skipjack tuna.

McMeekin and Olley (1986) have discussed the uses and limitations of several methods for monitoring spoilage in foods. For example, a chemical indicator can be combined with an enzyme-substrate system to measure the cumulative effect of time and temperature, but the chemical indicator must have the same temperature characteristics as the spoilage being monitored.

Other Considerations

Deterioration of tuna following frozen storage has not been studied thoroughly.

Nevertheless, histamine formation could occur during the handling of fish in preparation for canning. In particular, histamine production by psychrotrophic bacteria is possible during the thawing process because of the prolonged periods involved (Baranowski and Pan, 1985; Pan, 1985). Furthermore, since the fish have not been eviscerated before freezing, a variety of intestinal bacteria are present that could contribute to decomposition and the accumulation of histamine (Olley et al., 1985).

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Appointments Announced for Seafood Marketing Council

Commerce Secretary C. William Verity has appointed 13 members to the National Fish and Seafood Promotional Council. The Council helps market fishery products and foster their sales nationwide. Established in the closing days of the last Congress, it consists of 15 voting members serving 4-year terms. Two other members were soon to be appointed. Harvesters, processors, and marketers are equally represented with regional groups. The new members are:

Northeast Region: James A. McCauley, president and chief executive officer, Point Judith Fishermen's Cooperative Association, Inc., Narragansett, R.I.; William J. Dowd, president and chief executive officer, Mrs. Paul's Kitchens, Inc., Philadelphia, Pa.; and Kenelm W. Coons, executive director, New England Fisheries Development Foundation, Boston, Mass.

Southeast Region: Phyllis S. Shaffer, co-owner, shrimp business, Isle of Palms, S.C., and John G. Petalozzi, president, Tampa Main Sea Products, Inc., Tampa, Fla.

Pacific Region: Katheryn K. Vanderpool, owner/operator, Billingsgate Fish, Honolulu, Hawaii; Terry Baker, president and chief executive officer, Arctic Alaska Seafoods, Inc., Seattle, Wash.; and Dixie A. Blake, marketing manager, Ocean Garden Products, San Diego, CA.

Alaska Region: Roseleen L. Moore, co-owner, Northern Enterprises, Homer, Alaska; Terry Gardiner, founder and partner, Silver Lining Seafoods, Ketchikan, Alaska; and Gregory M. Carr, vice-president for merchandising, Carr's Quality Centers, Anchorage. Member-At-Large (Inland Fisheries): Nancy L. Abrams, marketing and culinary consultant, Chicago Fish House, Chicago, Ill. And, Member-At-Large (Nutrition Education): Mary D. Stiedemann, manager, Nutritional Marketing Services (General Mills, Inc.) Minneapolis, Minn.

The Council, which is made up of experts who have general fishery knowledge as well as other specialized experience such as familiarity with marketing, product development, public relations, or consumer education, will hold its first meeting in early December in Washington, D.C. Members receive no salary.

Top U.S. and Mexican Fishery Officials Meet

The schools of northern anchovy and Pacific sardine that feed and spawn off the coasts of Baja California, Mex., and the State of California recognize no international borders in their travels. Called "transboundary fish stocks" by scientists, the silvery swarms are a valuable resource shared by both the United States and Mexico. According to Izadore Barrett, Director of the National Marine Fisheries Service's Southwest Fisheries Center at La Jolla, Calif., these are the essential facts which underlie the first formal MEXUS-PACIFICO meeting held at the Center on 10 and 11 August 1987.

The idea of conducting cooperative fisheries research on projects of mutual interest on the western coast of the states of Baja California, Mex., and the U.S. Pacific Coast had its beginnings in the Pacific Coast Memorandum of Agreement in the fall of 1986 when the Mexican Instituto Nacional de la Pesca and the Southwest Fisheries Center of the National Marine Fisheries Service, an agency in the National Oceanic and Atmospheric Administration, agreed that such a program was in the best interests of both countries. Further groundwork was laid at the preparatory meeting in La Paz where scientific committees were formed on fisheries monitoring and analysis of fisheries resources.

The U.S. delegation was to be headed by Anthony J. Calio, Under Secretary of Commerce and Adminstrator of the National Oceanic and Atmospheric Administration, and included William E. Evans, NOAA Assistant Administrator for Fisheries, Fishery Attache for Latin America Howard O. Ness, E. Charles Fullerton, Director of the National Marine Fisheries Service Southwest Region, Izadore Barrett, Director of the Southwest Fisheries Center, and Robert Fletcher, Deputy Director, California Department of Fish and Game. Mexico was represented by Secretary of Fisheries Pedro Ojeda Paullada, Ambassador Fernando Castro y Castro, Alfredo Laguarda, Director of the Instituto Nacional de la Pesca, and others.

The U.S. and Mexican scientists met for several days before the formal meeting to outline specific action for exchange of scientific data and research to be undertaken by both countries on such fish species as anchovy, sardine, jack mackerel, and Pacific mackerel in 1988. In addition to the scientific meetings, Dr. Calio was to meet Secretary Ojeda Paullada for government to government discussions on fisheries cooperation between the two countries.

"I believe that the MEXUS-PACIFICO Agreement will provide significant scientific and economic benefits to both countries since it provides, for the first time, a formal arrangement for the coordination of joint fisheries research," SWFC Director Barrett explained. He added, "Although the present focus is only on four fish species, our hope is that eventually it will include collaborative work between Mexico and the United States on a much broader range of living marine resources of mutual interest.

NOAA Ship Completes Deepwater Shrimp Survey

The NOAA ship *Townsend Cromwell* completed a 31-day survey of the deepwater Hawaiian "ono" shrimp, *Heterocarpus laevigatus*, in October, according to Richard S. Shomura, Director of the NMFS Southwest Fisheries Center's Honolulu Laboratory. This bright red shrimp, which is harvested by traps set in waters as deep as 2,500 feet, is of considerable interest to the local fishing industry for its development potential.

To determine the shrimp's spatial distribution and overall abundance, 212 sets were made of large pyramid-shaped shrimp traps at depths of 1,200-3,000 feet around Kauai and Niihau, according to Darryl T. Tagami, Chief Scientist on the survey. The shrimp caught were generally large, averaging 1.2 ounces each. A typical catch for a trap set overnight was 15 pounds at Niihau and 8 pounds at Kauai. Peak abundance of shrimp was between depths of 1,500 and 1,800 feet. A deepwater camera with strobe was also deployed on the bottom at the trapping sites to gain a better understanding of shrimp density, behavior, and habitat. The survey is part of a stock assessment program at the Honolulu Laboratory to determine the resource potential of the deepwater shrimp fishery in Hawaii. The information collected will prove useful to local shrimp fishermen and for management of the fishery as it develops.

Silver Hake Stocks Are Slowly Growing

The NMFS Northeast Fisheries Center has reassessed the stocks of Northwest Atlantic silver hake: The Gulf of Maine-Northern Georges Bank stock and the Southern Georges Bank-Middle Atlantic stock. Biomass of both stocks is increasing slowly. Consequently, the catch from the Gulf of Maine-Northern Georges Bank stock could increase to 23.6 million pounds in 1987 from 18.7 million pounds in 1986 without affecting (i.e., no increase in) stock biomass for next year (1988), "assuming that the level of recruitment is equal to the average of the last five years". The catch from the Southern Georges Bank-Middle Atlantic stock could increase to 27.8 million pounds in 1987 from 22.3 million pounds in 1986 without affecting stock biomass for next year, "again assuming average recruitment."

NMFS Laboratories Will Be Jointly Used

The National Oceanic and Atmospheric Administration (NOAA) has accepted a proposal from the State of New Jersey that it will build a joint-use laboratory at Sandy Hook, N.J., to replace a National Marine Fisheries Service (NMFS) laboratory which burned there in September 1985. In addition to NMFS, the facility would be used by the 28 schools of the New Jersey Marine Consortium, Rutgers University's Institute of Marine, Coastal, and Estuarine Sciences, the New Jersey Department of Environmental Protection, and others.

Total cost will be about $11.2 million, of which $7.2 million would be attributable to the NOAA portion. NOAA would lease its part of the facility from the state. NOAA, the state, and National Park Service representatives were scheduled to meet to discuss needed agreements, possible legislation, and scheduling.

One of numerous NMFS facilities along U.S. coasts, the Sandy Hook installation has been in existence since the 1960's. It specializes in the study of mid-Atlantic fishes and their habitats, with emphasis on recreational species. Much of the laboratory's work in recent years has been focused on the New York Bight. Since the loss of the facility to an arsonist, scientists and technicians of the Commerce Department agency have been functioning in makeshift quarters.

Earlier this year, via separate agreement, the State of Maryland agreed to share the facilities of another NMFS fisheries research laboratory in Oxford, Md. The 13,000 square-foot laboratory, owned by the Commerce Department's National Oceanic and Atmospheric Administration and located on the Tred Avon River, houses 22 biologists and other Federal workers with NOAA's National Marine Fisheries Service. It has long been considered one of the U.S. East Coast's preeminent research centers for work on fish and shellfish diseases.

According to the agreement, signed 24 April 1987 by Anthony J. Calio, undersecretary for NOAA, and Torrey Brown, secretary of Maryland's Department of Natural Resources, the state will assume the day-to-day costs of running the facility, although NOAA will retain ownership of the laboratory. Research at the laboratory will stay centered around shellfish diseases, NOAA said. State researchers will concentrate on work in the Chesapeake Bay, especially threats to the area's valuable oyster population, and NMFS scientists are continuing their research on diseases in fish and shellfish in the United States and throughout the world. Calio characterized the cooperative agreement as a formalization of an already effective relationship between NOAA and the state, saying that the Federal government will be able to maintain its important research activities and Maryland will be able to use valuable "wet lab" facilities.

Bluefin Tuna Aging to Become More Reliable

NMFS Northeast Fisheries Center (NEFC) scientists have been assisting their counterparts at the Southeast Fisheries Center (SEFC) this year by meeting tuna purse seining vessels as they unload their catches and by collecting otoliths (ear stones) from three tagged Atlantic bluefin tuna in the vessels' catches. These are the first otoliths collected from tagged tuna in the Federal government's 33-year-old tuna tagging program which began at the NEFC's Woods Hole Laboratory and is currently administered by the SEFC's Miami Laboratory.

Bluefin tuna are easy to age up to about age 4 because of size differences, but after age 4 the sizes at different ages can overlap, forcing scientists to rely on otoliths or other similarly hard body parts to decipher age. Tuna otoliths should portray tuna age and growth much the way rings on tree trunks portray tree age and growth, but there has never been ver-

ification that the light-dark bands in tuna otolith cross-sections are reliable annular marks. These recent collections by NEFC scientists of otoliths from three tuna that had been tagged many years ago at a small (i.e., known-age) size, should establish the degree of reliability of present and future tuna age-and-growth data, and thus the degree of reliability of present and future management regulations which are based on such data.

Helicopter Used to Help Count Dolphins

The National Oceanic and Atmospheric Administration (NOAA) dispatched a dozen scientific observers, two research ships and a helicopter to the eastern tropical Pacific in August to survey populations of dolphins. The 4-month expedition is part of a 5-year dolphin study by the Commerce Department agency's National Marine Fisheries Service (NMFS) that began in 1986. The NMFS Southwest Fisheries Center (SWFC), located in La Jolla, Calif., is the agency responsible for the dolphin study.

The NOAA Ships *McArthur* and *David Starr Jordan* made the voyage: the *McArthur* left San Diego 30 July and the *Jordan* followed on 5 August 1987. Each ship carried a team of observers for estimating the number of dolphins in a school, and the *Jordan* was equipped with a helicopter pad and a Hughes 500-D helicopter from which observers photographed schools of dolphins.

Last year at this time, the same two NOAA ships left San Diego and covered the same area of the 5 million square miles of the eastern tropical Pacific that will be covered in this year's cruise. This 5-year program to monitor the abundance of stocks of dolphins in the eastern tropical Pacific was begun as a result of an amendment in 1984 to the Marine Mammal Protection Act. After reviewing the Bill for reauthorization in 1984, Congress mandated the NMFS to design and implement a program to monitor the relative abundance of dolphin stocks in the eastern tropical Pacific.

The eastern tropical Pacific is the only area in the world where some schools of yellowfin tuna swim beneath dolphin herds. Tuna fishermen search for schools of dolphins as an indication of tuna. They round up the dolphins with speedboats and encircle dolphins and tuna with huge seine nets. Although most of the dolphins escape or are released by fishermen over the nets, some become entangled and drown. Last year more than 126,000 dolphins were accidentally killed in the eastern tropical Pacific by yellowfin tuna fishermen from Ecuador, Mexico, Panama, the United States, Vanuatu, and Venezuela. Under Federal law, U.S. fishermen are limited to the accidental take of 20,500 of the mammals annually. Last October, NOAA banned U.S. tuna fishermen from setting their nets on dolphins 2 months before the end of the fising season because, for the first time, the U.S. quota had been reached.

According to Izadore Barrett, SWFC Director, the helicopter carrying a pilot and two observers was to fly over dolphin schools and photograph them with a special Navy camera, designed for filming from high-speed, low-flying aircraft. "This method," he said, "will give us a much more accurate idea of the porpoise population, including the size of the schools of dolphins and the species involved. And at the same time, observers on deck will also be making estimates of dolphin schools. Then we'll use the estimates of schools size from the photographs taken from the helicopter to calibrate the accuracy of the observers' estimates from the deck of the ship."

"Headstarted" Ridley Caught and Released

A sea turtle caught accidentally in a shrimp trawl at Matagorda Bay, Tex., in August was an endangered Kemp's ridley reared in a Federal restoration program for the species, according to the Texas Parks and Wildlife Department. The turtle was caught by Tom Price of Port Lavaca, who noticed the 15-pounder had a National Marine Fisheries Service (NMFS) tag on its right front flipper. He recorded the tag number before returning the animal to the water.

NMFS officials subsequently identified the turtle as one of a group of ridleys produced from eggs collected at Rancho Nuevo, Mex., in 1984. The eggs were incubated at the NMFS laboratory in Galveston, Tex., and the young turtles were released into the Gulf of Mexico off Padre Island on 21 May 1985. The turtle traveled about 76 miles, gained about 14 pounds, and increased its carapace (shell) width by 7.5 inches in the 15 months, according to TPWD fishery technician Randy Kelley. The Federal/state restoration is aimed at reestablishing a breeding population of the sea turtles in Texas. Persons catching tagged sea turtles, or encountering stranded or dead individuals, are asked to contact an office of the TPWD, NMFS, U.S. Fish & Wildlife Service, or the Texas Marine Science Institute at Port Aransas. Kelley said that about half of all turtles caught that appear to be dead actually are still alive. A live turtle often can be resuscitated by elevating its posterior above the level of its head and keeping its shell and skin moist for 24 hours. In all cases, a permitted authority should be notified of any actions taken, said Kelley.

Fish Oil Health Studies Aided by NMFS Research

NMFS research on fish oil extraction and purification has cleared the way for a greatly-expanded national program of research into the value of eating fish to human health. The Commerce Department agency's Northwest and Alaska Fisheries Center in Seattle, Wash., has announced the development of a system for refining inexpensively highly purified omega-3 fatty acids in fish oils, previously manufactured at extremely high cost.

These fatty acids in the human diet are widely believed to reduce rates of cardiovascular disease, arthritis, and other inflammatory ailments, as well as certain neurological and metabolic disorders. Using products made possible in quantity by the work of John Spinelli, the Center's Utilization Research Division director, the National Institutes of Health will coordinate a national program of research to

investigate this theory.

The manufacture of omega-3 compounds previously cost up to $2,000 per gram; the new method ultimately may bring the cost down to $5 a gram or less, Spinelli said. Heart of the system is a 6-foot stainless steel column in which "supercritical" carbon dioxide is introduced to fish oils containing the desired fatty acids. By varying the temperatures—up to 250°F—and the pressure—up to 2,500 p.s.i.—inside the column, scientists can dissolve and isolate the components of fish oils, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), the two believed most beneficial to human health. The system, which presently can produce 70 grams per day of over 90 percent-pure EPA, and 40 grams of DHA, will be installed in the National Marine Fisheries Service's Charleston, S.C., laboratory, while research continued in Seattle on a larger unit, designed to produce up to 4.5 kilograms (10 pounds) per day.

Ice Edge Study Begins in Arctic

A research team led by the National Oceanic and Atmospheric Administration (NOAA) left for the Arctic in August in an effort to understand better how the ice edge moves south in the fall, disrupting millions of dollars worth of industrial operations. Led by NOAA's Carol Pease of the Pacific Marine Environmental Laboratory in Seattle, Wash., the group of Federal, academic, and industrial researchers travelled to the Beaufort and Chukchi Seas off Alaska to study the ice edge as the freeze-up begins.

Within 3 months, ice will cover most of the Beaufort and Chukchi Seas, and will move south into the Bering Sea. As it advances, fishermen, oil drillers, and tug and barge operators must modify, and in some cases suspend, operations for the winter. Accurate prediction of ice conditions is crucial, according to Pease, because drilling rigs need 2-4 weeks' notice of anticipated conditions, and suppliers for North Slope oil operations, and northern Alaskan villages, must remove their barges before it closes in.

"We don't know whether the ice moves south as it does in the winter when the icepack grows in the north and is blown south, or whether the water along the leading edge freezes in place," she said. "If we don't know what mechanism causes the freezing, we can't predict its advance." The NOAA ship *Surveyor*, which will provide an operational base during most of the project left Nome on 16 August, to return in mid-September. On 10 October it will take the party back to the ice edge for another 2-week study.

Meters will be moored in all three seas to measure currents, water temperature, and conductivity. Automated weather stations will be installed at Icy Bay, Bearing Strait, and east of Nome. A helicopter crew will place instruments to record wind and air temperature and pressure along the icepack's leading edge. From the end of October until about Thanksgiving Day, researchers will work in Norton Sound, using a small boat and a helicopter. A long-term goal of the studies is to enable a joint NOAA-Navy Ice Center to predict accurately the extent of sea ice at any given time and how the ice edge advances over time. Participating are scientists from NOAA's Pacific Marine Environmental Laboratory, the University of Washington, the Naval Post Graduate School, and Science Applications International Corporation. The Office of Naval Research funds the project.

New Reporting Rules for Gulf Reef-Fish Fishermen

Final regulations implementing the mandatory reporting requirements outlined in the Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico became effective 23 October 1987, according to Craig R. O'Connor, Acting Director, Southeast Region, National Marine Fisheries Service (NMFS). The statistical reporting system, designed by NMFS and approved by the Gulf of Mexico Fishery Management Council, makes mandatory a previously voluntary reporting program for commercial fishermen, dealers and owners/operators of headboats and initiates a mandatory program for persons fishing traps. All persons fishing reef-fish traps, selected commercial fishermen fishing for reef fish by other means and selected headboat owners and operators will be required to maintain and submit logbooks providing data on catch, effort and fishing location. Commercial dealers and processors selected by the Director, Southeast Fisheries Center, will continue to report the weight and value of reef fish handled each month. Commercial vessels, charter vessels and headboats will be inventoried by the Center Director on an annual basis. There are no mandatory reporting requirements for charter vessel owners and operators at this time.

"The information being requested is essential to improving our management efforts for reef fish resources in the Gulf," said O'Connor. "We seek industry's cooperation in obtaining this vital information." All information collected is confidential and may be released to the public only in aggregate form that does not disclose proprietary or confidential information. Copies of the final rule containing the mandatory reef fish reporting requirements may be obtained from Mark F. Godcharles, National Marine Fisheries Service, 9450 Koger Boulevard, St. Petersburg, FL 33702, telephone (813) 893-3722.

Method Okayed to Check Contents of Fish Blocks

The Association of Official Analytical Chemists has approved a method developed at the Northeast Fisheries Center's Gloucester Laboratory for determining the relative proportions of fish fillets and minced fish flesh in fish blocks containing both items. (A fish block is a large frozen block of fused fish flesh from which such products as fish sticks are obtained.) The newly approved method is the first step in allowing fish blocks which contain both items to be graded by U.S. Department of Commerce inspectors. Results of the method are also admissable in a court of law. For further information, contact Robert J. Learson, FTS 837-9313 or (617) 281-3600.

Abalone Culture in Japan

Adam G. C. Body

Introduction

Abalone, known as awabe in Japan, is a popular and traditional food maintaining a good, consistent market value. Up to about 1960, management of the fishery included measures such as restrictions on harvesting times, banning of fishing in certain areas, minimum size regulations, and rules concerning fishing methods and licensing of fishermen.

By 1963, it was apparent that the abalone populations, as well as other fish stocks, could not maintain themselves under the sustained fishing pressures. Once seed stocks were successfully transplanted from areas of high spatfall, aquaculture research centers were set up in each of Japan's 37 coastal prefectures, funded jointly by the prefectural and national governments. This article briefly describes the abalone fishery in Japan, and discusses developments at the Iwate Prefectural Aquaculture Center which specializes in production of abalone seedlings for sale to fishing cooperatives around Japan.

Japan's Abalone Fishery

The annual yield of abalone in Japan is stable at about 5,000 metric tons (t) (meat plus shell) and the value of the fishery was about ¥10 billion (A$50 million) in 1975. The major commercial species are *Haliotis discus*, which is distributed in the warmer Kuroshio current-influenced areas, and *H. discus hannai* in the colder waters.

Abalone harvest runs 3 months following the spawning season which is October-December for *H. discus* and July-October for *H. discus hannai*. In warmer waters, abalone are generally collected by divers, but in colder waters fishermen use rods and hooks from boats. The latter method is inefficient but it helps to maintain stocks.

Most abalone fishermen's cooperatives maintain ponds or cages for:

1) Holding abalone stocks so advantage can be taken of seasonal price fluctuations; and

2) growing seed abalone, obtained from hatcheries, for a year before they are released at 2 years of age and 3.5-4 cm diameter.

Pond and cage types include concrete or stone enclosures in shallow places along the coast, ponds on land utilizing pumped seawater, cages hung from rafts, and cages over rocky areas on the seabed. Care is taken to ensure an adequate flow of water over the ponded or caged abalone so that oxygen levels are maintained in excess of 3 ml per liter.

The abalone are fed every 4-5 days in the warmer months and every 7-10 days in winter. The food is mainly brown algae, although green and red algae are also used. Abalone of 9 cm diameter fetch a wholesale price of around ¥500 (A$2.50) each and retail for A$3.50 to A$4.00. Prefectural hatcheries supply year-old seed at about A$0.20 each, and private hatcheries charge about twice that price.

Abalone Life Cycle and Ecology

Abalone live in rocky areas in the sublittoral zone along the coasts. They are nocturnal, hiding under rocks and in crevices during the day. At night they crawl about on the rocks by means of their strong, muscular foot, in search of food. Abalone feed on many types of macroalgae (seaweed), but prefer particular types. Relationships have been shown to exist between diet and shell pigmentation. Feeding activity is positively correlated with temperature within an optimum range which varies between abalone species. *H. discus hannai* is most active when the water temperature is 15°-20°C, and feeding is most voracious 2-3 hours after sunset and 2-3 hours before sunrise.

H. discus hannai takes 4-5 years to reach commercial size (9 cm), depending on environmental factors such as water temperature, food availability, water quality, and competition for food. Abalone are preyed on by many sea creatures, such as octopus, starfish, crabs, whelks, sea urchins, rays, sharks, and many fish species. Young abalone are more prone to being eaten than the larger ones, which are more protected by their larger shells.

When mature, female abalone show an olive green coloration of the ovary and males have an ivory colored testis. At

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spawning time, *H. discus hannai* tend to congregate. Spawning occurs just after sunset when the males release sperm which triggers spawning by the females. The bright green eggs which measure about 0.2-0.25 mm diameter are fertilized, then sink to the bottom. *H. discus hannai* spawn 1-1.5 million eggs per 100 g wet body weight plus shell. The eggs hatch in 12-15 hours at the swimming trocophore stage, and by 30 hours the larvae have developed a functional foot and are ready to settle. At 20°C, settled spat of *H. discus hannai* grow 0.03-0.04 mm per day.

The Iwate Prefectural Aquaculture Center

This hatchery complex, built in 1977 at a cost of ¥1.7 billion (A$8.5 million), has the capacity to produce 10 million 1-year-old *H. discus hannai* seed per year, as well as sea urchin (0.5 million a year), flatfish fry (1.2 million per year) and ayu (0.5 million a year). Abalone seed is sold to fishermen's coops, and the other species are released locally within the prefectural waters. Details of the center are shown in Table 1.

Water temperatures in the Iwate prefecture area range from 5° to 25°C. The abalone hatchery is in use during the late summer and autumn when the water temperature averages 20°C. Brood stock is held in special conditioning tanks. Researchers have found that abalone require a certain amount of time at set temperatures to attain full-gonadal maturity. *H. discus hannai* becomes fully mature after 120 days at 20°C. A 12:12 hour light:dark cycle must be maintained, along with plenty of food for the developing abalones. Populations of the warmer water species, *H. discus*, require higher values to attain full sexual maturity.

At the Iwate Aquaculture Center, ripe abalone are stimulated to spawn by taking the following steps:

1) Take abalone from the water 1 hour before the beginning of the dark period.
2) Leave abalone dry, at room temperature, for 1 hour.
3) Place abalone in seawater that has been UV (2537 A) irradiated.
4) Raise the water temperature to 23°C over 30 minutes, hold for 1 hour, and then lower back to 20°C.

The spawning success rate is generally better than 90 percent at the Center, providing properly conditioned abalone are used.

Fertilized eggs are collected on sieves and gently washed before being placed into 15-liter acrylic larval-rearing vessels at a concentration less than 30 eggs per ml. The batch method of rearing the larvae is employed and the water is changed twice daily. The larvae do not require feeding until they settle, which takes about 100 hours at 20°C. Larval-rearing water is filtered and UV irradiated immediately before use.

Settlement of larvae is on 400 mm × 300 mm corrugated plastic sheets arranged vertically in 2 m × 1.5 m × 0.6 m settling tanks. About 600,000 spat are settled in each tank so an average of 2,000 individuals set on each sheet. Settlement sheets are prepared carefully before use to ensure maximum success. Settling takes place over 4-5 hours at 20°C. Following settlement, water is exchanged at the rate of 30-50 percent per hour.

Preparation of the settlement plates is vitally important to achieve good results. Clean plates are left in flowing seawater for 2 weeks to allow a primary bacteria and algal community to develop. Young abalone are then allowed to graze on the plates for a further month. Immediately prior to use for settlement, the plates are collected. This must be done with care to ensure no abalone are forcibly taken off the plates. Therefore, the plates are collected during the day when the abalone are hiding away from the light. Settlement plates from which the abalone have been forcibly removed achieve far inferior results.

Spat Growth

Settled spat grow about 0.03 mm per day feeding on diatoms adhering to the settlement plates, and when they reach 2-5 mm, they are sorted into size groups. There is always a large variation in growth rate between individuals within a cohort, and it is necessary to keep the larger ones separate from the smaller ones. Ethyl p-aminobenzoate (100 ppm) is used to anesthetize the shellfish and keep them from sticking to each other; this makes them easier to sort using different sieve sizes. Sorted abalone are placed back on corrugated sheets (400 mm × 330 mm) which are put into cages, then into fiberglass troughs (20 m × 2 m × 0.6 m). Shade cloth covers the troughs so light intensity approximates that at a depth 5-10 m under water.

A diet of seaweed and 15-20 percent fishmeal is fed once a day to the abalone. Maintenance includes daily cleaning of debris from the bottom of the toughs and regular sorting of the abalone into size groups. The temperature and dissolved oxygen content of the water is monitored continuously. Survival rates and production costs are given in Table 2. When the abalone are almost 1 year old and ready for sale to fishermen's coops, they are fed seaweed exclusively in preparation for their transfer to ongrowing ponds.

Table 1.—Data on the Iwate-ken Aquaculture Center.

Location:	Ofunato, Iwate-ken, Japan, lat. 39°1'N, long. 141°40'E.
Seawater temperature range:	5°-25°C.
Seawater salinity range:	34-36 ppt.
Total area:	28,465 m^2.
Water pumps:	3 × 30 kW, cap. 200 t/hour each. 3 × 55 kW, cap. 400 t/hour each.
Water filters:	7 sand filters, each 3.3 m high × 3.0 dia., cap. 200 t/hour. 2 sand filters, each 1.8 m high × 2.1 m dia., cap. 50 t/hour.
Water heating capacity:	630,000 kcal/hour.
Water cooling capacity:	35,000 kcal/hour.
Air pump capacity:	1,020 m^3/hour.
Abalone seed growing troughs:	100 × 22 m long × 1.5 m wide × 0.6 m deep.

Table 2.—Survival rates and production costs for abalone.

Age	Survival rate	Production cost per individual ($A)
0-1 year	5-7 percent	0.15-0.20
1-2 years	60 percent	0.35-0.40
2-5 years	60 percent	

NMFS Scientific Reports Published

NOAA Technical Report NMFS 47. Sindermann, Carl J. (editor). **"Reproduction, maturation, and seed production of cultured species."** (Proceedings of the Twelfth U.S.-Japan Meeting on Aquaculture, Baton Rouge, Louisiana, October 25-29, 1983, under the U.S.-Japan Cooperative Program in Natural Resources (UJNR).) February 1987, iii + 73 p.

SUMMARY

Included are 13 papers by authorities from Japan and the United States on topics including recent trends in mariculture and seed production, Kuruma prawn maturation, brown algae production in Japan, red sea bream seed production, oyster and seed oyster production, U.S. penaeid shrimp culture, Malaysian prawn larval rearing systems, red swamp crawfish culture, triploid channel catfish production, a bullfrog ovulatory stimuli, and treatment of fish hatchery water to remove solids and turbidity.

NOAA Technical Report NMFS 48. Lenarz, William H., and Donald R. Gunderson (editors). **"Widow rockfish, proceedings of a workshop, Tiburon, California, December 11-12, 1980."** January 1987, iii + 57 p.

SUMMARY

Presented are reports and reviews covering widow rockfish, *Sebastes entomelas*, biology, ecology, ageing and growth, U.S. west coast fisheries, diet, behavior, commercial passenger fishing vessel landings, maturity, plus descriptions of reared larvae of six species of *Sebastes*.

NOAA Technical Report NMFS 49. Harding, Stephen M., and Mark E. Chittenden, Jr. **"Reproduction, movements, and population dynamics of the southern kingfish, *Menticirrhus americanus*, in the northwestern Gulf of Mexico."** March 1987, iii + 21 p., 10 figs., 8 tables.

ABSTRACT

Menticirrhus americanus in the northwestern Gulf of Mexico mature at 150-220 mm TL and 12-14 months of age, with males maturing when 10-40 mm smaller than females. Spawning occurs within a broad period from February through November with two discrete peaks which coincide with the periodicity of downcoast alongshore currents (towards Mexico) in spring and fall. This species occurs at depths of less than 5 to 27 m, being most abundant at 5 m or shallower. Young-of-the-year recruit primarily at 5-9 m or shallower and gradually expand their bathymetric range. Age determination by length frequency is feasible in *M. americanus* but not as simple as in species that spawn in one major period of the year. Only one or two spawned groups normally predominated at any one time and no more than three co-occurred with few possible exceptions. Observed mean sizes were 138 mm TL at 6 months, and 192 and 272 mm at ages I and II, respectively. Typical maximum size was 296-308 mm and typical maximum age is probably 2-3 years. The largest fish captured were 392 and 455 mm. Observed sex ratio was 1.2 females to 1 male. Weight, girth, and length-length regressions are presented.

NOAA Technical Report NMFS 50. Ropes, John W. **"Preparation of acetate peels of valves from the ocean quahog, *Arctica islandica*, for age determinations."** March 1987, iii + 5 p., 4 figs., 1 table.

ABSTRACT

Techniques are described for preparing acetate peels of sectioned valves of ocean quahogs, *Arctica islandica*, for age determinations. The respective sequence of preparation begins by sectioning left valves oriented to include a single hinge tooth, bleaching to remove the heavy periostracum, embedding the valves in an epoxy resin, grinding and polishing the embedments to a high luster, etching the exposed cut valve surfaces, and applying sheet acetate with acetone. Annuli are clearly defined relative to growth increments in the peel preparations for all sizes and ages of ocean quahogs.

NOAA Technical Report NMFS 51. Croxall, John P., and Roger L. Gentry (editors). **"Status, biology, and ecology of fur seals."** (Proceedings of an international symposium and workshop, Cambridge, England, 23-27 April 1984.) June 1987, v + 212 p.

SUMMARY

Thirty-two papers and reports cover the symposium's goals of reviewing 1) the scope and results of present behavioral, ecological, and physiological research on each fur seal species and the present status, recent population trends, history of exploitation, and rate of recovery from exploitation for each species; and 3) to compare demographic, behavioral, and ecological traits that may be related to recovery for each species; and 4) to identity important needs and opportunities for fur seal research, stressing comparisons and collaborative efforts.

NOAA Technical Report NMFS 52. Huppert, Daniel D. (editor). **"Limited access alternatives for the Pacific groundfish fishery."** May 1987, iii + 45 p.

SUMMARY

Included are 8 papers on limited access, reviewing what it is and its application to the Pacific groundfish fishery, along with an appendix presenting elements of a proposal for a groundfish trawl license moratorium by the Fishermen's Marketing Association and Coast Draggers Association.

NOAA Technical Report NMFS 53. Witzell, Wayne N. (convener and editor). **"Ecology of east Florida sea turtles."** (Proceedings of the Cape Canaveral, Florida, Sea Turtle Workshop, Miami, Florida, February 26-27, 1985.) May 1987, iii + 80 p.

SUMMARY

Presented are 11 papers and abstracts on the biology, ecology, and mortality of sea turtles in the Cape Canaveral, Fla., marine ecosystem, along with data on environmental problems, population surveys, landings, and sexing techniques and sex ratios for immature loggerhead sea turtles along the U.S. Atlantic coast.

Healthful Attributes of Fish and Fish Oils

"Seafoods and Fish Oils in Human Health and Disease" by John E. Kinsella has been published by Marcel Dekker, Inc., 270 Madison Avenue, New York, NY 10016. The author is with the Institute of Food Science at Cornell University, Ithaca, N.Y., and here he reviews and relates the effects of the omega-3 polyunsaturated fatty acids (PUFA's) found in fish oils to their interactions with the metabolism of the n-6 fatty acids and the effects of the n-3 fatty acids on human health.

The author begins by reviewing the relationship of dietary fats and cardiovascular disease and eicosanoid metabolism. Presented then are longer reviews of the effects of dietary n-3 PUFA consumption learned from both human and animal feeding trials.

Chapter 3 discusses the effects of ingestion of fatty fish, marine oils, or n-3 PUFA's on human plasma and platelet characteristics, production of prostaglandins by vessel walls, levels of urinary prostaglandins metabolites, and on erythrocyte characteristics, etc.

Chapter 4 reviews studies with animals regarding the effects of the n-3 PUFA's on cardiac, plasma, platelet, and other blood characteristics, on aortic tissues, hepatic characteristics, lung and kidney lipids, adipose tissue, and on cerebral and neurological characteristics.

A very short chapter discusses dietary PUFA's and cancer, and another calculates U.S. fish and n-3 PUFA consumption. Other chapters review cholesterol and fat soluble vitamins in fish oils, factors affecting the safety of fish oils, and the status of edible fish oil processing and technology. In addition, the author summarizes the health implications of dietary fish and fish oils and assesses needs for future research. Lastly, he lists the potential sources of fish oil and presents oil content data on the fatty fish in U.S. waters.

The book is indexed (each chapter carries its own bibliography) and provides a good update of recent knowledge on an important topic, and suggests worthy areas for future research. Hardbound, it is available from the publisher for $99.75, and will be a handy source of data and reviews for those in the field of food science, either as researchers, dieticians, nutritionists, biologists, etc.

NUTRIENT VALUES OF FINFISH AND SHELLFISH PRODUCTS

Publication of the revised edition of the U.S. Department of Agriculture's Agriculture Handbook No. 8 on fish and fish products has been announced by that agency. It is Agriculture Handbook No. 8-15, **"Composition of Foods: Finfish and Shellfish Products...Raw, Processed, Prepared,"** by the Nutrition Monitoring Division. This is the 15th in the series of publications which update and expand the USDA's widely recognized Agriculture Handbook No. 8, which was last revised in 1963. The newly revised version is being issued section by section, each of which contains a table of nutrient data for a major food group.

The 15th section of the Handbook was prepared to serve as a basic general reference for data on nutrients in finfish and shellfish products and presents values for 174 items. It is published in looseleaf form to facilitate updating. Each page contains the nutrient profile for a single food item, given on the 100 g food basis, in two common measures and in the edible portion of 1 pound as purchased. Values are provided for energy, proximate composition (water, protein, lipid, carbohydrate, and ash), nine mineral elements (calcium, iron, magnesium, phosphorus, potassium, sodium, zinc, copper, and manganese), nine vitamins (ascorbic acid, thiamin, riboflavin, niacin, pantothenic acid, vitamin B-6, folacin, vitamin B-12 and vitamin A), individual fatty acids, total saturated, monounsaturated, and polyunsaturated fatty acids, cholesterol, and 18 amino acids. The standard error of the values on the 100 g basis and the number of samples on which the values are based are included in the tables.

To obtain copies of Agriculture Handbook 8-15, send check or money order (no cash) to the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. The price is $10.00 and the stock number is 001-000-04497-4. A 25 percent discount is allowed on orders of 100 or more to one address.

Tropical, Subtropical Fisheries Conference Proceedings Available

Publication of the **"Proceedings of the Eleventh Annual Tropical and Subtropical Fisheries Conference of the Americas"**, compiled by Donn R. Ward and Barbara A. Smith, has been announced by the Texas Agricultural Extension Service's Marine Advisory Service Program, Texas A&M University, College Station, TX 77843.

Several of the contributions deal with market development for various fishes, including underutilized species. Two are on crawfish product economics and markets and on crawfish market development. Warren Rathjen discusses potential fish species for promotion and impediments to their adoption by consumers. Other papers cover salting and drying of cannonball jellyfish and of selected underutilized southeastern U.S. finfishes for the international market. And J. A. Gooch and M. B. Hale describe the edibility characteristics and instrumental texture and color parameters for 40 southeastern U.S. finfishes.

Other papers discuss screening of sodium bisulfite on shrimp (a modified Monier-Williams approach), influence of washing and cooking on sulfite residuals on treated shrimp, an evaluation of alternatives to sulfiting agents as melanosis inhibitors in raw shrimp, fluctuations in calico scallop production, soft-shelled blue crab production research, processing menhaden for conventional food products, minced intermediates, and surimi, and more.

In addition, five papers on seafoods and human health are presented, including three on fish oils and human health studies, and one each on larval ascaridoid nematodes in seafood products, and transfer of a *Gambierdiscus toxicus* toxin

to black sea bass tissues. The 304-page paperbound volume is available from the publisher for $10.

The **"Proceedings of the Tenth Annual Tropical and Subtropical Fisheries Conference of the Americas,"** compiled by Ward and Granvil D. Treece, was dedicated to the late Melvin Waters, longtime NMFS technologist. The volume includes very useful author and subject indexes to the first 10 volumes.

Presented are eight contributions on shrimp, including a look at processing costs and value added in Gulf shrimp in 1982, economic factors determining shrimp prices, three models for forecasting U.S. shrimp prices, SO_2 levels in iced and frozen shrimp, methods for determining SO_2 levels, and others. Articles on crawfish include processing time effects on the meat, evaluation of differences between red swamp and white river crawfish meat, holding temperature and body condition of Finland crawfish, and brine freezing of crawfish. Other articles include thermal process studies of alligator meat, on-board handling to improve the shelflife of fish, quality changes in thawed lobster tails, demand for major reef fishes in the U.S. southeast, dried kingfish as a potential for export, and others. The 307-page paperbound volume is available for $15 from the publisher.

Care and Handling of High Quality Fishes

"Quality Handling of Hook-Caught Rockfish" by Brian Paust and John Svensson, published by the Alaska Sea Grant College Program, 590 University of Alaska, Suite 102, Fairbanks, AK 99701, is a small but very good handbook that relates tested methods for proper handling of rockfishes (genera *Sebastes* and *Sebastolobus*) to maintain the highest quality and thereby earn top dollar for them. The methods are aimed at those fishing for rockfish on small- to medium-sized fishing vessels. Soak times of 2-4 hours are recommended by the authors and, if gaffing is necessary, gaff only in the head, they say. Bleeding, very important, is thoroughly discussed and illustrated with diagrams of veins and arteries and photos of the proper procedures. Also covered are washing, dressing, holding, filleting, packing, shipping, and sanitation. Printed on a tough, water resistent paper, the handbook is Marine Advisory Bulletin 20 (price not listed).

The University's Marine Advisory Bulletin No. 28 is the **"White Fish Processing Manual"** by Chuck Jensen which was developed as a supplemental handbook for a course in white fish processing technology. Quality control is the entire thrust of this manual and it is a good one, discussing programs to maintain high quality, starting with delivery, bleeding fish, onboard storage, keeping quality control records, clean-up and sanitation, importance of employee attitude toward sanitation, detergents and sanitizing or sterilizing agents, chlorine compounds, hypochlorites, cleaning schedules, personal hygiene for workers, product examination records, fillet quality and defects, packaging, suggested quality inspection forms, and more. Then, chapter II reviews Alaskan, Federal and industry regulations affecting processors, and chapter III surveys the raw materials themselves—types of white fish, catch methods, etc. Chapters IV, V and VI review considerations for plant siting, layout, and design and type of cutting operation. Chapter VII then reviews employee incentive programs; chapter VII, financial considerations; and IX, tools of the trade. Chapter X then reviews selection of markets and market strategies briefly, followed by Appendix A—the NMFS fishery products inspection manual. Appendix B lists material specifications, shipping requirements, warranty, and other technical data on fish blocks, odor, color, size uniformity, and more. Paperbound, the 75-page manual is a fine, succinct guide to producing high quality fish product; price not listed.

Soft-Shelled Blue Crab Research

The **"Proceedings of the National Symposium on the Soft-Shelled Blue Crab Fishery,"** edited by Harriet M. Perry and Ronald F. Malone, has been published by the Gulf Coast Research Laboratory, Biloxi, Miss. The symposium was sponsored by the Southeast Marine Advisory Service Network and the Sea Grant Mid-Atlantic Advisory Service Network, and was hosted by the Louisiana and the Mississippi-Alabama Sea Grant institutions.

The soft-shelled blue crab industry has grown considerably in recent years and the symposium presents much of the advancements in research and development that have been attained. Contributions range from a thorough review of the physiology of the blue crab during a molt by Charlotte P. Mangum et al., to shorter state-by-state reviews of blue crab developments. In addition, Phyllis T. Johnson discusses blue crab viruses and the diseases they cause, while Ronald Sizemore relates the involvement of Vibrios in soft crab mortalities. Another article by W. S. Otwell and J. A. Koburger presents new data on the microbial and nutritional attributes of soft-shelled crabs. Other presentations provide data on the soft-shelled crab fisheries, blue crab shedding systems, aquaculture system design considerations, profitability components in closed shedding systems in the Gulf of Mexico, development of a Japanese export market, and more. Short working group reports are also presented, as are the discussions in the Open Forum. Paperbound, the 128-page volume (MASGP-86-017) is available from the Mississippi-Alabama Sea Grant Consortium, P. O. Box 7000, Ocean Springs, MS 39564-7000 at $7.00 per copy.

Commercially Important Shellfish and Seaweeds of the Pacific Northwest

Publication of **"Shellfish & Seaweed Harvests of Puget Sound"** by Daniel P. Cheney and Thomas F. Mumford, Jr., has been announced by the University of Washington Press, P.O. Box C-50096, Seattle, WA 98145-0096. The volume is another in the U.W. Sea Grant Program's excellent "Puget Sound Books" series and is a thorough and well illustrated review of the region's important shellfish and seaweed species and their harvests and culture.

Outside the region, chapter 7 will be of considerable interest for its review of several seaweed species, their uses and harvesting methods, and the development of seaweed culture. Washington has over 500 species of seaweeds, and culture studies of *Iridaea* and *Gigartina* have been tried and dropped; nori culture has continued and other species are also harvested. In addition, Appendix C lists actual or potential uses for nearly 100 species of seaweeds.

Following an introductory overview, the authors discuss the resources and fisheries (and culture, where applicable) for oysters (Pacific and Olympic) and clams (six species), clam industry economics and future, blue and California mussel, *Octopus dofleini*, squid, scallops, and abalone. Another chapter reviews the Sound's Dungeness crab resources, harvests, and management. Shrimp, sea urchin, and sea cucumber resources, harvests, management, and market development are also presented. The book reflects the many changes that have occurred in the shellfish and seaweed industries, and the authors say that Puget Sound offers many more opportunities for development of many of these fisheries.

Other Appendices review the physical and biological characteristics of Puget Sound, the physical and environmental features of commercially harvested pandalid shrimp in Puget Sound, and pertinent State regulations. Indexed, the 164-page paperbound volume is available from the publisher for $8.95.

Tunas and Development in the Pacific Islands

The Pacific Islands Development Program of the East-West Center in Hawaii has conducted considerable research on tuna development in the emerging nations of the Pacific Islands region, from which several interesting publications have resulted. One of these is **"Tuna Issues and Perspectives in the Pacific Islands Region,"** edited by David J. Doulman, which carries a wide variety of papers on the tuna resource of that region and the factors that impinge on its development. An introductory section presents papers on tuna fisheries management in the region, the impact of the LOS on tuna resources, and biological perspectives on development of industrial tuna fisheries. Other sections deal with distant-water tuna fisheries of Japan and the United States and the purse seine and longline tuna fisheries. Four papers review artisanal tuna fisheries in the region and three others deal with the history and role of the Forum Fisheries Agency, fisheries cooperation in the Nauru Group, and a look at global tuna markets. Doulman sums it up then with a look at prospects and directions for the region's tuna fishery. Paperbound, the 314-page book is available from the Publications Office, East-West Center, 1777 East-West Road, Honolulu, HI 96848 (price not listed).

Available from the same office also is **"The Development of the Tuna Industry in the Pacific Islands Region: An Analysis of Options,"** (cost is $10.00), also edited by Doulman. Here is a thorough overview of the region's domestic tuna industries, distant-water fleet operations, and regional fisheries cooperation. Also reviewed are the important U.S., Japanese, Canadian, European, and Middle East tuna markets, especially from the view of accessibility for the Pacific Island nations.

Likewise, important competitors for those markets, such as Mexico, the Philippines, and Thailand, are reviewed, compare, and analyzed. Also discussed and summarized are the international business operations in the global tuna market. And, finally, a section on development options and issues presents papers on financing a tuna project, public investment and taxation, packaging tuna projects, development and financing of fishery-related infrastructure, and social and environmental aspects and impacts of tuna projects.

Two other PIDP papers also available are **"Development of the Australian Tuna Industry"** by Greg Crough and **"The U.S. Tuna Market: A Pacific Island Perspective"** by Dennis M. King. The former discusses two main aspects of the development of the Australian tuna industry—first, its history from small-scale origins in the 1930's through its full development. The second aspect relates the involvement of corporations, particularly transnational ones, in the development of the industry. Cost is $20.00.

King's report examines the large U.S. tuna market and makes suggestions on how the Pacific island nations, by controlling 40 percent of the global tuna supply, could have a major impact on all world markets and develop strategies to gain more market control and negotiate more effectively with the large U.S. tuna companies. Cost also is $20.00.

Global Harvest and Trade in Salmon

Publication of **"Salmon: Economics and Marketing"** by Susan A. Shaw and James F. Muir has been announced by Timber Press 9999 S.W. Wilshire, Portland, OR 97225. The authors are senior lecturers with the University of Stirling in Scotland. Salmon and salmon products from both northern and southern hemispheres compete in marketplaces worldwide, and the authors have produced a thorough review of the economics of this resource that should be of interest to those involved in salmon harvests and regulation, marketing, and aquaculture. Introductory material describes the various salmon species and their life cycles (along with their different production characteristics and positions in the marketplace), fishing methods, artificial enhancement and ranching, salmon farming, and handling and processing techniques used.

Chapter 2 then outlines the primary patterns of salmon supply and trading patterns for salmon and salmon products, while chapters 3-5 provide a closer look at the supply side of the equation, exploring such issues as salmon management, farming and ranching, and the implications for production costs and the availability of supplies. Chapter 6 details the various methods and amounts of salmon processing, while chapter 7 looks at the distribution channels and the marketing of salmon. Finally, chapter 8 discusses the workings of the salmon markets and the demand for salmon and offers a look at salmon markets in the 1990's. The authors expect salmon supplies to increase in the next decade, with a doubling for some like the Atlantic salmon, and thus conclude on an opti-

mistic note. The 270-page hardbound volume is indexed, includes a glossary, and is available from the publisher for $34.95 plus $3 postage and handling.

The Future of Marine Fisheries

"Fisheries Development: 2000 A.D.," edited by K. K. Trivedi, and published by A. A. Balkema, Rotterdam, constitutes the proceedings of a sequel conference to the FAO World Fisheries Conference held in 1984 and presents wide-ranging and detailed discussions of EEZ management, aquaculture prospects, and international trends in the marketing of marine fisheries products which will be of interest to those involved in future fisheries development.

Organized by the Association of Indian Fishery Industries, the meeting and volume are slanted toward Indian fisheries development, but most of the presentations also provide useful insights into the question of how to develop and manage the world's fisheries to meet the growing need for those products. Besides the "green revolution," or production of more cereal grains, Indian officials are also seeking a "blue revolution" to spur greater production of fish and fishery products, and that is the thrust of this publication.

Following a review of the World Fisheries Conference and its assessments and recommendations, papers include a review of the worldwide effect on fishing of creation of EEZ's by Peter Hjul; the EEZ creation and development of India's marine fisheries by P. V. Dehadrai; management and development of the Australian fishing zone by R. Bain; and then a discussion on management of EEZ's.

The session on fisheries development strategies included papers on marine fisheries development to the year 2000 by W. Philip Appleyard; India's strategy for marine resource development by N. P. Singh; and development of deep-sea fishing by J. V. H. Dixitulu. T. V. R. Pilay then presents an international perspective on aquaculture while Jaques Perrot reviews French achievements in fish culture. Prospects for and perspectives on aquaculture over the next 15 years is then related by S. N. Dwivedi.

Wolfgang Krone reviews trends in the international markets for fisheries products, while D. P. Verboon relates the marketing of fishery products in Australia, and S. G. Sundaram discusses the problems and prospects for exporting marine products from India. Final presentations summarize the conference papers and provide a list of sound recommendations for those involved in the development and marketing of fisheries and fish products, especially those connected with the less developed nations. Hardbound, the 263-page volume is available from International Publishers Service, Inc., c/o Mercedes Distribution Center, Inc., 160 Imlay St., Brooklyn, NY 11231 for $43.50.

Rockfishes of the Northeast Pacific

Publication of a **"Guide to Northeast Pacific Rockfishes, Genera *Sebastes* and *Sebastolobus*"** by Donald E. Kramer and Victoria M. O'Connell has been announced by the Alaska Sea Grant College Program, 590 University Ave., Room 102, Fairbanks, AK 99709-1046. The handbook, Marine Advisory Bulletin 25, was compiled and published to simplify the identification of the rockfishes found along the Alaska coast, and is intended for those who do not have the experience or time to use a key for rockfish identification. It should accomplish its purpose handily, for the drawings and photographs are large and very well done. Indeed, the color photos may well be the most important part of the book, for some species, such as *Sebastes nebulosus*, can be identified by color alone. Many species, though are very similar to others and the user will have to employ the full diagrams and descriptions to be sure what species is in hand.

The book will also be very useful and of interest well south of Alaska, too, as the authors have included all rockfish species found off British Columbia, and most of the species in Washington and Oregon waters. Rather than grouping species by color or characteristics, they are listed alphabetically by scientific name. Thus, the users will have to leaf through the guide and check all the possibilities and characteristics to determine what species he has. For some, that may be a minor annoyance, but for the average angler or commercial fisherman it is probably just as fast; 37 species are included in the volume. Also included are indexes to scientific and common names and a list of selected references. The book is spiral bound, printed on extra-heavy, coated paper for long use, and is available from the publisher (price not listed).

Locating Fisheries Data and Related Information

The Aquatic Sciences and Fisheries Information System (ASFIS) is an international information system for the science, technology, and management of marine and freshwater environments which is maintained jointly by the FAO, IOC, UN OETB, along with the assistance of the various national ASFIS partners. The ASFIS information outputs include the computer searchable Aquatic Sciences and Fisheries Abstracts (ASFS) database and its printed abstracts, contents tables, meetings register, and serial titles list. And it now includes an updated **"Aquatic Sciences and Fisheries Thesaurus,"** subtitled "Descriptors Used in the Aquatic Sciences and Fisheries Information System," compiled by E. Fagetti, D. W. Privett, and J. R. L. Sears and published for the FAO by Cambridge Scientific Abstracts, 5161 River Road, Bethesda, MD 20816 as ASFIS Reference Series No. 6 Revision 1.

The new thesaurus was conceived to correspond to the objectives of the ASFIS system and permits the subject indexing and retrieval of information on all aspects of aquatic sciences and technology, exploitation of living and nonliving resources, related policy, social and economic aspects; processing and marketing of aquatic products, as recorded and stored in the ASFA database. It supercedes the old FAO Fisheries Circular 344, "Thesaurus of Terms for Aquatic Sciences and Fisheries" published in 1976. Clearly, the volume will be a great help to those who want to locate appropriate materials in the hundreds of thousands of records compiled during 1971-85. The Thesaurus covers only subject index terms and should be used in con-

junction with the ASFIS Guidelines for Subject Categorization and Indexing and the other ASFIS indexing tools—i.e., the geographic authority list and the NODC Taxonomic Code. (Price not listed.)

Seaweed Ecology, Herring Parasites, Siphonophores, and Antarctic Fish Study

"Advances in Marine Biology," volumes 23 and 24, edited by J. H. S. Blaxter and A. J. Southward and published by Academic Press, Inc., 1250 Sixth Avenue, San Diego, CA 92101, present several very interesting reviews ranging from population and community ecology of seaweeds to the ecology of deep-sea hydrothermal vent communities, biology of Pycnogonida and Siphonophores, herrings and their parasites, physiology of Antarctic fishes, and more.

Volume 23 begins with "Population and Community Ecology of Seaweeds," by A. R. O. Chapman of Canada's Dalhousie University, in which he provides an extensive synthesis of the several score recent studies on ecology seaweed, including related ecophysiological studies. J. Le Fèvre then presents a paper entitled "Aspects of the Biology of Frontal Systems," especially with regard to frontal structures in northwest European waters and their influence on pelagic ecosystems. The author provides an overview of shelf-sea tidal fronts and discusses models, frontal circulation patterns, bottom water near tidal fronts, internal waves, and estuarine and coastal fronts. In addition, an overview of fronts and plankton is provided, including the annual phytoplankton cycle, high seas fronts, red tides and fronts, and the accumulation biotype.

Finally, J. Frederick Grassle of the Woods Hole Oceanographic Institution discusses the ecology of deep-sea hydrothermal vent communities, beginning with a brief history of their discovery, and reviewing their physical characteristics (distribution, age, chemical components of hydrothermal fluids), the various organisms common (and uncommon or absent) at the vents. He then discusses faunal distribution and density, zoogeography and ecology (i.e., feeding relationships, metal tolerance, geologic history, and metabolic rates of the deep-sea communities). The volume has subject and taxonomic indexes and provides a cumulative list of titles and authors in the series. It is available in the U.S. at $76.00 or from Academic Press, Inc. (London) Limited, 24-28 Oval Road, London NW1 7DX at £42.00.

Volume 24 presents five reviews, beginning with F. Arnaud and R. N. Bamber on "The Biology of Pycnogonida," or sea spiders, exclusively marine invertebrates with about 1,000 species in 84 genera. This paper collates and summarizes the current knowledge on pycnogonid biology for marine biologists. Topics reviewed include zoological characteristics, physiology and function, life cycles, interrelationships with other organisms, zoogeography, and palaeontology and systematic affinities.

"Siphonophore Biology" by G. O. Mackie et al. is an up-to-date treatment of the group, stressing the ecological and physiological aspects. Discussed is body form (development and coloniality), systematics and evolution, distribution and migration, physiology and behavior, and nutrition, ecology, and ecological importance. K. MacKenzie then discusses relationships between the herring, *Clupea harengus* L., and its parasites, reviewing the protozoan and metazoan parasites reported from that species, host range and specificity, life cycles and zoogeography of the parasites, sexual differences in herring to parasitic infection, parasites as biological tags, and the contribution of parasitic disease to natural mortality.

The chapter on comparative physiology of Antarctic fishes by J. A. Macdonald et al. presents a fine summary of the progress in the field made over the last 25 years and suggests potential areas for further study. Most of the work reviewed was done on fishes of McMurdo Sound area, though work from areas like the Scotia Sea and other areas is included, too. Following brief introductory discussion of the evolution of Antarctic fishes, the kinds of fish there and their capture, and the usefulness of their study, the authors discuss adaptive radiation and buoyancy, stenothermy and temperature selection, cryoprotective agents or "antifreeze," metabolism and growth, blood and the transport of oxygen, enzymes and other proteins, and Nototheniid neurobiology. The final chapter by N. J. P. Owens reviews natural variations in ^{15}N in the marine environment, presenting methods and calculations, isotope effects and fractionation, variations in ^{15}N in nature, source studies, and food chain dynamics. Hardbound, the 473-page volume is available from the publisher for £48.00

Predation Effects in Aquatic Communities

Publication of **"Predation, Direct and Indirect Impacts on Aquatic Communities,"** edited by Charles Kerfoot and Andrew Sih, has been announced by the University Press of New England, 3 Lebanon Street, Hanover, NH 03775. The volume is an outgrowth of a symposium sponsored by the Ecological Society of America on "Competition, Predator Avoidance, and the Traits and Distribution of Aquatic Organisms" held in Ft. Collins, Colo., in 1984. However, those reports have been considerably augmented with another 18 solicited papers.

The editors have arranged the contributions in three main subject areas: 1) Direct and indirect influences of top predators on food web dynamics; 2) chemically mediated interactions between predators and prey; and 3) research on the ways that predators modify prey behavior, life styles, and morphology. The contributions are broad in scope, ranging from stability analysis to natural fluctuations in systems, and studies of response time ranging from minutes to days, months, and even million of years.

The volume's central theme is that the mere presence of a predator can alter the relationship between two or more competitors in various and important ways and the 24 essays treat a variety of important topics on organisms in both freshwater and marine environments. This book is divided into sections on direct interactions, types of indirect interactions, food web dynamics (cascading

trophic responses and influences along indirect pathways), behavioral and morphological responses, evolutionary responses mediated by chemicals, ecological adjustments in time and space, and local and regional extinctions. The contributions provide a handy and useful synthesis of recent findings and should be a fine introduction to a developing field. In addition, they indicate potentially fruitful directions for future research in this field. Hardbound, the 386-page volume is indexed and each chapter carries its own literature citations. It is available from the publisher for $60.00.

Experiences in Limited Entry

"Fishery Access Control Programs Worldwide," edited by Nina Mollett, and published by the Alaska Sea Grant Program as Report 86-4 constitutes the "Proceedings of the Workshop on Management Options for the North Pacific Longline Fisheries." Included are 20 wide-ranging presentations which provide considerable insight into the problems and progress in this aspect of fisheries management. The impetus for the workshop was an Alaska Sea Grant project to reopen the dialogue on management alternatives for that state's longline fisheries, and one of the first steps was to try to learn what the worldwide experience had been with the various limited access programs—what had shown success and which ones had failed and why. In introductory papers, R. Bruce Rettig provides an overview of other national experiences with limited entry and Hugh Richards and Abby H. Gorham review the complex controversy that surrounded the U.S. halibut fishery moratorium.

Other papers discuss regulation of Norwegian fishing fleet capacity, limiting Norway's purse seine fleet capacity, management of Iceland's demersal fisheries, Japan's vessel reduction program in the tuna and skipjack fisheries, implementation of an ITQ-based (property rights) fisheries management system in New Zealand, developments and alternative strategies in Australian fisheries, and individual transferable quotas in the Australian southern bluefin tuna fishery.

Also reviewed are various management schemes for selected Canadian fisheries, surf clam management under the Magnuson Act, California's limited entry programs, Washington's limited entry experiences, efficiency and distributional aspects of Alaska's limited entry program, and a review of management schemes in developing countries. Paperbound, the 366-page volume is available from the Alaska Sea Grant College Program, 590 University Ave. Suite 102, Fairbanks, AK 99701-1046 (price not listed).

Some Notes on Mariculture

"World Salmon Farming: An Overview with Emphasis on Possibilities and Problems in Alaska" by Curt Kerns has been published by the University of Alaska's Sea Grant College Program, 590 University Ave., Suite 102, Fairbanks, AK 99709-1046 as Marine Advisory Bulletin #26. Written primarily for an Alaskan audience, this bulletin provides a handy overview of the beginning and, more recently, the explosive growth in salmonid culture, particularly in Scandianavia. The author also looks at current and potential markets and relates opportunities for increased salmon farming. He also outlines the culture methods and reviews the present status of salmon farming around the globe, needs in research and training, and assesses the potential for Alaska, its salmon culture competitors, the benefits and potential disadvantages for the state, and makes some projections for future production and salmon markets. Paperbound, the 43-page report costs $2.00.

Also from Alaska Sea Grant Program is Aquaculture Note #11, "Where to Get More Information on Farming Marine Algae in High Latitude Waters" by Curt Kerns. The bulk of the note is an extensive listing of nearly 400 books, articles, and reports, given alphabetically by author, of titles relating to the farming of marine algae. In addition, the author provides notes on Alaskan culture regulations, research assistance available, aquaculture organizations involved, periodicals that carry articles on seaweed culture, and addresses of organizations working with seaweeds. Also included are subject and systematic indexes and a geographical index. It would be a useful reference for anyone contemplating the culture of seaweeds; cost is $1.00.

Likewise, Aquaculture Note #9, also by Kerns, tells "Where to Get More Information on Small-Scale Aquaculture," by providing related bibliographical data on general technical manuals and manuals devoted specifically to salmon, trout, and shellfish. Again, data is provided on pertinent aquaculture organizations and periodicals; cost is $2.00.

Cataloging the Humpback Whales

University of Alaska Sea Grant Report 87-1, edited by T. Frady, is **"Workshop on Humpback Whale Photo Identification: A Summary of Proceedings,"** which relates the discussions in Seattle in April 1986 of humpback whale researchers regarding a computerized humpback whale photo-identification catalog system being developed by the NMFS National Marine Mammal Laboratory (NMML). At the time, no formal data sharing existed among Pacific humpback whale researchers, many of whom had private whale photo collections ranging from <100 to >2,000 collected over 5-25 years.

This publication presents a summary of the discussions and lists variables for NMML photo identification system, Pacific humpback whale photo-ID catalog areas and subareas, research goals, and illustrates fluke patterns used, along with a fluke section map and additional details on the program. The 12-page paperbound report is available from the Alaska Sea Grant College Program, University of Alaska, 590 University Avenue, Suite 102, Fairbanks, AK 99709-1046 (price $4.00).

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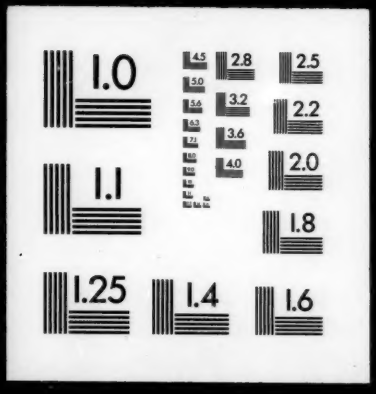
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